

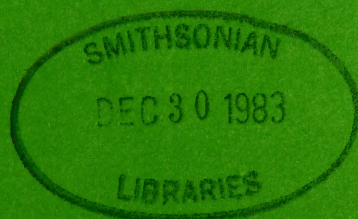
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## Precise Observations of Minor Planets at Sydney Observatory During 1982

N. R. LOMB

ABSTRACT. Positions of 1 Ceres, 3 Juno, 4 Vesta, 7 Iris, 39 Laetitia, 51 Nemausa and 704 Interamnia obtained with the 23 cm camera are given.

The programme of precise observations of selected minor planets which was begun in 1955 has been continued and the results for 1982 are given here. This, however, is likely to be the last paper in the series. The methods of observation were described in the first paper (Robertson 1958). All the plates were taken with the 23 cm camera (scale 116" to the millimetre). Two or four exposures were taken on each plate, depending on the brightness of the planet. The number of exposures on each plate is indicated in Table 1. On some plates of the two brightest objects, 1 Ceres and 4 Vesta, an objective grating was used to give side images dispersed in right ascension; on these plates the side images of the minor planets were measured.

In Table 1 are given the means of the positions for all the exposures using all six reference stars at the mean of the exposure times. The result for the first pair of images was compared with that for the last two by adding the motion computed from the ephemeris for the plates with four exposures. The r.m.s. differences were 0".009 Sec  $\delta$  in right ascension and 0".14 in declination.

No correction has been applied for aberration, light time or parallax, but the factors give the parallax correction when divided by the distance. The column headed "O-C" gives the differences between the measured positions (corrected for parallax) and the position computed from the ephemerides supplied by the Institute for Theoretical Astronomy in Leningrad. The ephemeris for 51 Nemausa was obtained from L.K. Kristensen (University of Aarhus, Denmark).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table 2 gives for each observation the positions of the reference stars and the six star dependences. The reference star positions were converted to standard coordinates for the calculation of six star dependences. The columns headed "R.A." and "Dec." give the seconds of time and arc with the proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed "Star" gives the number of the star in the SAO catalogue or the zone and number of the star in the AGK3 catalogue. The column headed "Vol." gives the volume of the SAO or AGK3 in which the star is listed. The first column gives a serial number which cross-references Table 1 and Table 2 and also the catalogue from which the reference stars were taken.

All plates were reduced by both the method of dependences and by first order plate constants using the same six reference stars. Equal results were obtained in each case, as could be expected due to the formal identity of the two methods. The r.m.s. residuals of the reference stars were obtained by taking for each star the mean residual from the plate constants fitted to the first and last pairs of images, summing the squares of these residuals in right ascension and declination for all stars on all plates with four exposures and dividing the result by the appropriate number of degrees of freedom. For SAO stars the r.m.s. residual was 0".69 (34 plates).

Using six star dependences instead of two sets of three star dependences, as had been employed in reducing observations from years previous to 1978, has the disadvantage that a direct measure of the uncertainties in the measured positions is no longer available and the uncertainties have to be found by indirect means. The method used was described in a previous paper (Lomb 1980). The standard errors calculated in this way are listed in Table 3. As there were no four image plates with AGK3 reference stars the 0".38 r.m.s. residual for AGK3 stars in 1981 was used in calculating the table.

The plates were measured by Miss E. Burdis, Miss D. Teale and Miss R. Skeers. The observers at the telescope were D.S. King (K), N.R. Lomb (L), W.H. Robertson (R) and K.P. Sims (S).

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*Sydney Observatory Papers No. 33.*
- Lomb, N.R., 1980. Precise observations of minor planets at Sydney Observatory during 1979. *J. Roy. Soc. N.S.W.* 113, 1-6  
*Sydney Observatory Papers No. 88.*

TABLE 1  
POSITIONS OF MINOR PLANETS

No.	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors		O - C		No. of Exp.
	h	m	s	o	i	"	s	"	s	"	
1 Ceres 1982 U.T.											
1793	Mar.	29.70988	15 43 07.787	-09 42 20.05	-0.023	-3.56	-0.043	+0.08	2	S	
1794	Apr.	01.70751	15 42 29.140	-09 39 29.74	-0.004	-3.56	-0.043	-0.08	4	S	
1795	Apr.	22.66023	15 31 36.426	-09 15 24.18	+0.051	-3.62	-0.000	+0.34	4	L	
1796	Apr.	28.62794	15 26 49.107	-09 09 13.81	+0.012	-3.63	-0.004	+0.66	4	K	
1797	May	04.61552	15 21 33.336	-09 04 31.53	+0.036	-3.65	-0.003	+0.52	4	R	
1798	May	17.57750	15 09 35.470	-09 02 11.37	+0.053	-3.65	-0.055	+0.35	4	S	
1799	May	24.54112	15 03 26.785	-09 06 44.94	+0.013	-3.64	-0.024	-0.44	4	K	
1800	June	17.46977	14 48 25.156	-10 00 14.87	+0.027	-3.51	+0.040	-0.03	4	R	
1801	June	22.45729	14 46 53.926	-10 18 45.68	+0.034	-3.47	-0.007	-0.48	4	L	
1802	June	29.41811	14 45 49.058	-10 48 26.53	-0.026	-3.40	+0.020	+0.49	4	R	
1803	July	16.39173	14 48 05.109	-12 16 44.81	+0.032	-3.19	+0.012	+0.44	4	S	
1804	July	26.35582	14 52 24.339	-13 16 41.53	-0.005	-3.04	-0.003	+0.07	4	K	
3 Juno 1982 U.T.											
1805	Apr.	21.78578	18 36 02.410	-07 46 11.18	+0.036	-3.85	-0.065	+0.26	2	L	
1806	May	04.73520	18 36 30.138	-06 47 51.38	-0.012	-3.98	-0.032	+0.49	2	R	
1807	June	01.66948	18 25 26.736	-05 10 20.17	+0.045	-4.20	-0.083	+0.57	2	L	
1808	June	22.59040	18 08 48.566	-04 48 13.88	+0.013	-4.24	-0.129	+0.18	4	S	
1809	July	16.49332	17 48 56.309	-05 33 01.83	-0.042	-4.14	-0.045	+0.75	4	S	
1810	July	21.48866	17 45 33.472	-05 50 55.00	-0.007	-4.10	-0.077	+0.86	4	R	
1811	July	28.47651	17 41 35.105	-06 19 49.61	+0.023	-4.04	-0.056	+1.21	2	S	
1812	Aug.	12.42336	17 36 31.945	-07 32 48.48	-0.004	-3.87	-0.011	+0.61	2	R	
1813	Aug.	19.39902	17 35 54.025	-08 10 06.13	-0.018	-3.78	-0.042	+0.35	2	R	
1814	Aug.	23.41092	17 36 02.755	-08 32 00.56	+0.052	-3.74	-0.041	+0.57	2	S	
4 Vesta 1982 U.T.											
1815	June	01.79287	21 39 38.522	-16 10 53.34	+0.011	-2.66	+0.072	+0.65	4	L	
1816	June	22.73763	21 50 25.340	-16 50 51.21	-0.006	-2.57	+0.096	-0.10	4	S	
1817	July	21.65403	21 43 54.344	-19 52 02.82	-0.006	-2.12	+0.077	+1.07	4	R	
1818	July	29.63899	21 37 59.586	-20 58 38.64	+0.029	-1.96	+0.143	+0.92	4	S	
1819	Aug.	09.59124	21 28 13.564	-22 28 07.53	-0.007	-1.73	+0.118	+0.24	4	K	
1820	Aug.	19.55263	21 18 56.432	-23 38 21.37	-0.023	-1.56	+0.121	-0.33	4	R	
1821	Aug.	23.54402	21 15 26.324	-24 01 44.20	-0.007	-1.49	+0.111	+0.30	4	S	
1822	Sep.	07.48657	21 05 08.101	-24 59 59.63	-0.039	-1.35	+0.106	+0.49	4	R	
1823	Sep.	24.45392	21 01 03.908	-25 10 26.31	+0.017	-1.32	+0.117	-0.15	4	S	
1824	Oct.	13.41061	21 06 58.379	-24 24 18.06	+0.032	-1.44	+0.074	+0.08	2	S	
1825	Oct.	18.40663	21 10 09.446	-24 03 58.09	+0.057	-1.50	+0.035	+0.50	4	S	
7 Iris 1982 U.T.											
1826	Feb.	03.73234	12 25 19.723	-10 48 26.02	+0.014	-3.39	+0.034	+0.21	4	L	
1827	Mar.	22.57962	11 53 34.630	-08 32 02.43	+0.007	-3.71	+0.011	+0.28	4	R	
1828	Mar.	29.55083	11 47 10.622	-07 44 39.01	-0.009	-3.82	+0.034	+0.26	4	S	
1829	Apr.	22.49502	11 30 42.397	-05 08 12.70	+0.056	-4.18	-0.080	-0.29	4	L	
1830	Apr.	29.45775	11 28 16.385	-04 32 44.18	+0.005	-4.25	-0.106	-0.34	4	R	
1831	May	25.38542	11 29 23.907	-03 23 32.00	-0.001	-4.41	-0.120	-0.54	2	R	
1832	June	17.34041	11 41 41.209	-03 43 06.56	+0.027	-4.36	-0.070	-0.20	2	R	

## PRECISE OBSERVATIONS OF MINOR PLANETS

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TABLE 1 (Cont.)  
POSITIONS OF MINOR PLANETS

No.	R.A. (1950.0)			Dec. (1950.0)			Parallax Factors		O - C		No. of Exp.	
	h	m	s	o	'	"	s	"	s	"		
39 Laetitia 1982 U.T.												
1833	May	24.76979	20 44 37.941	-08 14 31.57	-0.011	-3.79	-0.008	+0.15	2	K		
1834	June	01.75393	20 47 18.080	-07 54 48.97	+0.002	-3.84	-0.015	+0.08	2	L		
1835	June	22.70415	20 47 17.205	-07 42 35.20	+0.026	-3.87	-0.032	+0.17	2	S		
1836	July	21.59957	20 31 20.317	-09 22 35.61	-0.019	-3.63	+0.005	+0.56	4	R		
1837	July	28.58604	20 25 45.284	-10 05 30.22	+0.010	-3.53	+0.054	-0.05	4	S		
1838	Aug.	09.54798	20 16 13.994	-11 28 34.81	+0.015	-3.34	+0.072	+0.34	4	K		
1839	Aug.	19.50594	20 09 22.387	-12 41 04.39	-0.017	-3.16	+0.026	-0.01	4	R		
1840	Aug.	23.50507	20 07 06.580	-13 09 41.72	+0.020	-3.09	-0.018	+0.20	4	S		
1841	Sep.	07.45035	20 02 01.157	-14 47 58.66	-0.013	-2.86	+0.024	+0.08	2	R		
1842	Sep.	24.42821	20 03 31.111	-16 13 49.43	+0.061	-2.66	-0.006	+0.27	2	S		
51 Nemausa 1982 U.T.												
1843	Mar.	29.69034	15 03 13.898	-07 38 08.09	+0.002	-3.84	-0.013	+0.59	2	S		
1844	Apr.	22.62065	14 49 53.035	-03 53 46.22	+0.018	-4.35	-0.004	+0.42	2	L		
1845	May	17.54544	14 29 18.486	-00 48 33.25	+0.040	-4.75	-0.013	+0.35	2	S		
1846	June	17.44298	14 18 09.626	-00 21 37.99	+0.009	-4.81	+0.018	+0.05	2	R		
1847	June	22.42947	14 18 44.403	-00 37 30.26	+0.008	-4.77	-0.007	-0.20	2	L		
1848	June	28.43082	14 20 18.689	-01 02 23.32	+0.059	-4.72	+0.042	+0.40	2	S		
704 Interamnia 1982 U.T.												
1849	Jan.	21.67346	10 02 38.529	-05 41 05.48	+0.028	-4.10	-0.053	+0.00	2	S		
1850	Mar.	16.49644	09 22 05.111	-04 21 20.47	+0.023	-4.29	-0.052	-0.27	2	L		
1851	Mar.	22.46031	09 19 17.692	-03 57 56.01	-0.031	-4.34	-0.041	+0.13	2	R		
1852	Mar.	29.47022	09 16 55.273	-03 30 55.31	+0.063	-4.40	-0.087	-0.78	2	S		

TABLE 2  
REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Vol.	Star	Depend.	R.A.	Dec.	No.	Vol.	Star	Depend.	R.A.	Dec.
1793	3	140681	0.125936	48.831	26.12	1797	3	140453	0.187707	25.943	59.32
SAO	3	140697	0.137305	18.282	54.86	SAO	3	140487	0.200078	26.755	09.47
	3	159467	0.157554	16.323	22.13		3	159224	0.146319	00.364	18.84
	3	140746	0.177822	50.825	26.42		3	159245	0.143762	22.995	16.15
	3	159515	0.197871	49.940	56.86		3	140537	0.182552	17.519	20.24
	3	140793	0.203512	31.628	07.37		3	140571	0.139582	36.888	50.28
1794	3	140681	0.219242	48.831	26.12	1798	3	140321	0.182084	33.442	54.65
SAO	3	140713	0.216919	28.541	27.00	SAO	3	140361	0.155698	34.077	19.71
	3	159467	0.141128	16.323	22.13		3	159083	0.185376	58.733	11.38
	3	140778	0.177581	23.343	58.34		3	140394	0.150093	23.234	15.99
	3	159515	0.109455	49.940	56.86		3	140412	0.174318	25.703	47.48
	3	140793	0.135674	31.628	07.37		3	140432	0.152430	35.288	33.07
1795	3	140571	0.164689	36.888	50.28	1799	3	140294	0.195047	07.978	32.99
SAO	3	140589	0.229048	24.977	38.55	SAO	3	140306	0.173176	10.167	19.73
	3	140598	0.107157	25.658	31.32		3	140307	0.196246	14.094	59.62
	3	140628	0.244369	08.361	25.67		3	140327	0.149290	18.246	47.87
	3	159383	0.074080	16.763	39.23		3	140341	0.158557	36.774	57.89
	3	140666	0.180657	33.491	40.96		3	140350	0.127684	52.822	13.23
1796	3	140518	0.144217	19.396	04.72	1800	3	158793	0.160047	42.433	15.34
SAO	3	140530	0.159530	48.791	52.06	SAO	3	140135	0.155043	24.772	24.88
	3	140537	0.141363	17.520	20.24		3	140162	0.154093	23.536	42.83
	3	159308	0.187767	06.612	27.68		3	158868	0.181123	38.215	06.76
	3	140587	0.172718	14.887	01.27		3	158886	0.179685	38.855	42.70
	3	140606	0.194404	03.045	02.20		3	140225	0.170009	44.241	22.38

TABLE 2 (Cont.)  
REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Vol.	Star	Depend.	R.A.	Dec.	No.	Vol.	Star	Depend.	R.A.	Dec.
1801	3	158806	0.197164	00.292	07.84	1812	3	141725	0.171650	20.157	35.37
SAO	3	155810	0.190506	38.223	20.08	SAO	3	141737	0.194747	37.323	38.33
	3	140150	0.176299	12.462	05.82		3	141792	0.183636	06.910	08.29
	3	158844	0.150073	26.273	58.94		3	141794	0.149001	17.060	57.32
	3	140178	0.142821	33.353	28.29		3	141835	0.145343	17.073	15.98
	3	158854	0.143137	46.116	40.68		3	141857	0.155623	38.934	59.35
1802	3	158772	0.212062	09.020	31.69	1813	3	141707	0.112881	00.976	35.27
SAO	3	158793	0.165697	42.433	15.34	SAO	3	141742	0.214471	18.149	36.32
	3	158800	0.239427	23.077	32.34		3	141756	0.093578	56.326	55.47
	3	158834	0.105996	46.771	44.39		3	141787	0.117894	35.791	11.30
	3	158868	0.174488	38.215	06.76		3	141811	0.267314	04.027	48.37
	3	158886	0.102331	38.855	42.70		3	141826	0.193862	38.798	15.46
1803	3	158783	0.193446	01.138	37.46	1814	3	141725	0.186779	20.157	35.38
SAO	3	158800	0.155314	23.077	32.34	SAO	3	141737	0.139737	37.323	38.33
	3	158825	0.217159	14.678	08.29		3	141763	0.196744	26.156	45.14
	3	158868	0.125790	38.215	06.76		3	141811	0.140492	04.027	48.37
	3	158900	0.176473	02.811	15.49		3	141818	0.174319	04.785	10.27
	3	158902	0.131818	09.600	34.86		3	141846	0.161930	53.017	15.13
1804	3	158845	0.135365	29.802	06.06	1815	3	164517	0.126780	11.769	19.66
SAO	3	158872	0.117242	54.086	06.56	SAO	3	164526	0.141610	44.515	45.62
	3	158876	0.196717	17.266	38.04		3	164585	0.153713	22.697	57.71
	3	158910	0.140181	52.608	10.94		3	164587	0.181805	32.331	54.02
	3	158921	0.235861	29.234	36.61		3	164624	0.186166	20.151	48.23
	3	158936	0.174634	30.669	33.97		3	164643	0.209925	08.633	07.79
1805	3	142401	0.219500	01.883	06.35	1816	3	164635	0.155877	32.845	34.15
SAO	3	142440	0.231111	54.638	24.71	SAO	3	164664	0.142835	31.426	00.88
	3	142447	0.143947	09.431	27.68		3	164673	0.169767	28.971	14.97
	3	142496	0.184922	25.746	01.58		3	164741	0.161096	36.729	39.32
	3	142504	0.089533	52.335	18.67		3	164774	0.192272	28.779	49.42
	3	142535	0.130988	24.817	01.80		3	164794	0.178155	41.432	01.53
1806	3	142406	0.155941	27.990	19.25	1817	3	164567	0.177539	47.686	24.37
SAO	3	142436	0.189297	42.743	28.33	SAO	3	190574	0.184233	11.538	25.72
	3	142450	0.146332	15.862	20.20		3	190622	0.174175	21.155	09.64
	3	142486	0.196182	51.488	17.89		3	164655	0.157883	54.529	25.64
	3	142504	0.171289	52.335	18.67		3	190683	0.157406	29.284	15.49
	3	142524	0.140959	53.105	16.16		3	164700	0.148764	21.632	07.63
1807	3	142264	0.189002	43.643	35.40	1818	3	190487	0.189769	54.311	37.01
SAO	3	142272	0.215673	19.310	20.08	SAO	3	190504	0.177414	47.673	25.80
	3	142323	0.140456	15.291	16.81		3	164567	0.153055	47.686	24.37
	3	142366	0.193996	58.887	07.44		3	190552	0.175504	41.207	23.42
	3	142370	0.111579	17.295	05.81		3	190594	0.157755	56.120	02.10
	3	142388	0.149294	01.227	14.33		3	190598	0.146502	16.823	34.48
1808	3	142091	0.130416	00.748	26.32	1819	3	190322	0.158484	44.085	15.21
SAO	3	142116	0.192422	07.208	16.99	SAO	3	190335	0.204953	23.608	50.13
	3	142132	0.106336	12.046	43.06		3	190391	0.135547	13.760	47.78
	3	142142	0.238023	54.985	33.19		3	190438	0.205768	35.909	54.01
	3	142162	0.125709	40.771	17.18		3	190472	0.122902	31.869	29.60
	3	142187	0.207094	53.154	20.18		3	190486	0.172347	52.315	11.14
1809	3	141877	0.196503	47.751	59.98	1820	3	190190	0.162482	49.581	11.79
SAO	3	141887	0.177337	53.964	50.85	SAO	3	190203	0.171230	40.174	24.15
	3	141906	0.182579	29.495	20.15		3	190248	0.159382	50.317	58.53
	3	141909	0.159356	54.724	04.63		3	190280	0.174993	56.618	30.25
	3	141961	0.151020	54.897	59.50		3	190322	0.163691	44.085	15.21
	3	141989	0.133206	13.601	55.23		3	190353	0.168221	33.178	04.01
1810	3	141842	0.233755	48.760	34.26	1821	3	190110	0.167271	08.639	37.25
SAO	3	141868	0.190980	08.697	41.41	SAO	3	190133	0.181008	24.227	09.65
	3	141877	0.202933	47.751	59.98		3	190190	0.148775	49.581	11.79
	3	141906	0.150625	29.495	20.15		3	190258	0.186208	35.264	14.66
	3	141909	0.109662	54.724	04.63		3	190271	0.152231	25.041	53.43
	3	141924	0.112045	54.591	29.12		3	190304	0.164506	30.746	22.98
1811	3	141792	0.174086	06.910	08.29	1822	3	189957	0.168683	35.730	23.15
SAO	3	141808	0.186340	28.333	53.00	SAO	3	189983	0.146534	30.789	29.49
	3	141811	0.133752	04.027	48.37		3	190006	0.187904	05.922	37.57
	3	141868	0.149807	08.697	41.41		3	190077	0.144280	02.818	04.57
	3	141877	0.204704	47.751	59.98		3	190104	0.189214	44.196	47.28
	3	141887	0.151311	53.964	50.85		3	190136	0.163385	33.706	52.77

TABLE 2 (Cont.)  
REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Vol.	Star	Depend.	R.A.	Dec.	No.	Vol.	Star	Depend.	R.A.	Dec.
1823	3	189874	0.200343	44.154	59.74	1834	3	144769	0.194473	46.493	07.01
SAO	3	189894	0.158694	47.514	05.99	SAO	3	144806	0.179184	41.961	00.48
	3	189984	0.125463	31.182	03.79		3	144812	0.185228	59.494	45.26
	3	189991	0.203853	01.586	53.29		3	144899	0.157991	07.499	01.80
	3	190074	0.170746	57.118	15.73		3	144921	0.141293	40.540	07.68
	3	190077	0.140902	02.819	04.57		3	144934	0.141829	18.785	33.39
1824	3	189975	0.196113	53.311	17.16	1835	3	144796	0.167012	06.631	39.52
SAO	3	190018	0.178681	57.642	01.35	SAO	3	144807	0.142094	47.910	43.64
	3	190019	0.187798	57.732	49.31		3	144818	0.200661	29.780	11.58
	3	190136	0.157122	33.706	52.77		3	144851	0.114395	12.980	45.39
	3	190154	0.144153	40.057	09.52		3	144897	0.212271	01.413	39.72
	3	190203	0.136132	40.174	24.16		3	144916	0.163567	23.089	09.03
1825	3	190061	0.175166	18.329	48.69	1836	3	144510	0.175550	53.907	22.67
SAO	3	190074	0.184914	57.118	15.73	SAO	3	163658	0.200331	20.989	09.78
	3	190133	0.182059	24.227	09.66		3	144543	0.142288	44.472	59.07
	3	190135	0.150409	32.511	06.79		3	144600	0.137253	39.508	11.04
	3	190179	0.149346	09.663	57.96		3	163718	0.185302	24.206	24.56
	3	190203	0.158106	40.174	24.16		3	144643	0.159276	31.176	11.83
1826	3	157241	0.180673	46.872	03.96	1837	3	163536	0.161491	33.789	22.99
SAO	3	138772	0.155142	00.533	41.03	SAO	3	163577	0.156354	55.609	05.21
	3	157281	0.189210	23.372	47.27		3	144438	0.175154	25.729	19.24
	3	138810	0.139672	16.389	28.22		3	144491	0.178766	43.374	13.68
	3	157336	0.186555	48.278	19.97		3	163647	0.157879	21.260	14.42
	3	157371	0.148748	43.386	27.37		3	163658	0.170356	20.989	09.78
1827	3	138456	0.210315	09.561	32.50	1838	3	163396	0.252446	09.908	00.95
SAO	3	138477	0.172534	18.594	47.94	SAO	3	163403	0.163933	37.006	34.90
	3	138487	0.191787	09.065	29.70		3	163438	0.257201	09.123	41.72
	3	138497	0.144613	32.952	26.81		3	163463	0.096976	35.279	01.10
	3	138515	0.155122	23.129	06.48		3	163498	0.095236	17.191	12.72
	3	138522	0.125628	05.715	50.98		3	163546	0.134208	11.766	57.11
1828	3	138394	0.152319	36.153	28.53	1839	3	163298	0.205612	29.415	09.44
SAO	3	138397	0.165386	56.353	48.85	SAO	3	163311	0.199216	28.138	29.21
	3	138434	0.182736	43.397	11.65		3	163314	0.189975	35.130	37.95
	3	138439	0.156848	00.251	08.29		3	163368	0.155229	24.002	30.22
	3	138450	0.162064	13.193	25.76		3	163395	0.123717	05.017	10.79
	3	138455	0.180648	03.098	21.48		3	163405	0.126251	39.142	19.95
1829	3	138235	0.210543	10.348	59.04	1840	3	163262	0.192169	19.783	04.15
SAO	3	138239	0.211290	56.743	54.88	SAO	3	163265	0.163804	37.433	50.04
	3	138262	0.188065	06.927	00.25		3	163303	0.200238	58.451	30.76
	3	138286	0.147434	41.092	58.07		3	163314	0.139247	35.130	37.95
	3	138301	0.136117	39.533	54.92		3	163361	0.136338	02.411	27.76
	3	138318	0.106551	25.495	05.18		3	163368	0.168204	24.002	30.22
1830	3	138198	0.162984	03.421	29.00	1841	3	163185	0.170044	21.872	16.75
SAO	3	138213	0.167867	44.243	16.42	SAO	3	163187	0.200253	26.200	34.17
	3	138218	0.160391	24.981	02.54		3	163232	0.101191	48.171	23.53
	3	138268	0.165457	33.063	53.58		3	163251	0.236888	34.717	10.42
	3	138276	0.172688	03.131	41.03		3	163283	0.118413	06.231	28.95
	3	138289	0.170614	23.469	52.09		3	163303	0.173211	58.451	30.76
1831	3	138213	0.194000	44.242	16.42	1842	3	163200	0.234462	42.914	53.16
SAO	3	138239	0.176329	56.742	54.88	SAO	3	163216	0.184565	49.287	19.48
	3	138244	0.173180	29.246	45.36		3	163255	0.219563	53.687	00.63
	3	138274	0.154911	47.961	38.94		3	163278	0.129978	52.379	35.99
	3	138276	0.153596	03.131	41.03		3	163322	0.155433	28.778	47.40
	3	138287	0.147984	02.045	38.30		3	163364	0.075999	08.328	15.28
1832	3	138334	0.161606	42.659	37.68	1843	3	140255	0.143991	14.618	26.71
SAO	3	138356	0.113727	28.669	53.38	SAO	3	140277	0.168657	57.814	57.07
	3	138361	0.215585	59.115	18.72		3	140313	0.147789	00.071	50.46
	3	138389	0.112705	31.262	08.32		3	140327	0.185644	18.246	47.87
	3	138400	0.228169	10.887	04.24		3	140358	0.179472	16.756	29.84
	3	138411	0.168208	14.370	15.95		3	140365	0.174447	01.147	21.14
1833	3	144746	0.186342	31.843	05.14	1844	3	140132	0.082122	06.306	35.82
SAO	3	144769	0.166073	46.493	07.01	SAO	3	140154	0.176911	32.100	41.63
	3	144780	0.188923	15.965	21.30		3	140189	0.208433	27.721	45.32
	3	144817	0.140121	27.450	04.60		3	140197	0.141570	13.788	17.87
	3	144851	0.176911	12.980	45.39		3	140223	0.210208	40.309	13.42
	3	144874	0.141630	40.456	59.57		3	140226	0.180756	45.747	27.68

TABLE 2 (Cont.)  
REFERENCE STAR POSITIONS AND DEPENDENCES

No.	Vol.	Star	Depend.	R.A.	Dec.	No.	Vol.	Star	Depend.	R.A.	Dec.
1845	8	- 0°1919	0.167256	39.483	52.05	1849	3	137291	0.136751	39.202	44.77
AGK3	8	- 1°1843	0.111854	44.729	10.91	SAO	3	137308	0.213630	57.446	32.86
	8	- 0°1922	0.225110	37.720	59.16		3	137322	0.086124	51.930	14.22
	8	- 1°1845	0.129153	28.202	07.19		3	137356	0.236907	31.645	55.41
	8	- 0°1927	0.212598	12.063	20.82		3	137359	0.136517	47.353	07.93
	8	- 1°1846	0.154029	33.887	48.54		3	137368	0.190071	26.398	24.73
1846	8	- 0°1903	0.160508	30.306	01.84	1850	3	136765	0.196694	49.915	21.11
AGK3	8	- 0°1904	0.166480	13.945	07.38	SAO	3	136783	0.136846	12.307	00.18
	8	+ 0°1737	0.161121	04.780	20.91		3	136811	0.216471	34.534	32.67
	8	- 1°1830	0.172659	10.158	20.24		3	136834	0.114940	59.770	52.52
	8	- 0°1910	0.173016	36.354	19.76		3	136874	0.209739	23.581	27.68
	8	+ 0°1743	0.166216	02.060	30.52		3	136891	0.125311	25.180	10.96
1847	8	- 0°1905	0.167548	15.881	55.07	1851	3	136760	0.232819	10.944	27.20
AGK3	8	- 1°1827	0.194488	04.175	28.51	SAO	3	136765	0.203449	49.915	21.11
	8	+ 0°1734	0.130384	53.234	57.25		3	136783	0.203362	12.307	00.18
	8	- 1°1832	0.205189	14.333	40.72		3	136798	0.132133	22.450	23.93
	8	+ 0°1741	0.142670	00.228	25.25		3	136807	0.115746	26.462	06.71
	8	- 0°1911	0.159721	59.049	46.61		3	136834	0.112490	59.770	52.52
1848	8	- 1°1827	0.228345	04.175	28.51	1852	3	136692	0.123406	34.635	26.16
AGK3	8	- 0°1906	0.208592	02.138	02.81	SAO	3	136729	0.170381	21.806	38.85
	8	- 0°1909	0.169914	32.555	05.28		3	136735	0.092578	46.969	12.99
	8	- 0°1916	0.099240	32.134	02.04		3	136765	0.239887	49.915	21.11
	8	- 2° 864	0.175923	04.155	03.74		3	136776	0.157305	32.435	26.68
	8	- 1°1838	0.117986	45.115	55.26		3	136796	0.216444	08.335	50.68

TABLE 3  
STANDARD ERRORS

		R.A.	Dec.
AGK3	2 image	0 <sup>S</sup> .012 sec δ	0".19
SAO	4 image	0 <sup>S</sup> .020 sec δ	0".29
SAO	2 image	0 <sup>S</sup> .020 sec δ	0".30

Sydney Observatory,  
Sydney, N.S.W., 2000.

## The Volatile Leaf Oils of *Melaleuca armillaris*, *M. dissitiflora* and *M. trichostachya*

JOSEPH M. BROPHY AND ERICH V. LASSAK

**ABSTRACT.** The composition of the steam-volatile leaf oils of *Melaleuca armillaris*, *M. dissitiflora* and *M. trichostachya* has been determined by the use of capillary gas-liquid chromatography and mass spectrometry. The oil of *M. armillaris* contained 1, 8-cineole as its main component whilst *M. trichostachya* leaf oil contained major proportions of both 1, 8-cineole and  $\alpha$ -pinene. *M. dissitiflora* was found to exist in two chemical forms characterized by oils rich in 1, 8-cineole and terpinen-4-ol respectively.

### INTRODUCTION

Following our earlier investigations of the volatile leaf oils of *Melaleuca* (Hellyer and Lassak, 1968; Lassak, 1979) we have now examined the oils of three species included by Bentham (1966) in the series *Spiciflorae*, *Melaleuca armillaris* Sm., *M. dissitiflora* F. Muell. and *M. trichostachya* Lindl. So far only the oil of *M. trichostachya* has been examined. Baker and Smith (1910) reported 1,8-cineole as the main component (ca 80% of the oil) together with small amounts of terpinyl acetate and possibly of  $\alpha$ -pinene in two samples of oil obtained from foliage collected near Gladstone in Queensland and Port Macquarie in northern coastal New South Wales. Since *M. trichostachya* does not appear to occur in its native state in eastern New South Wales, the Port Macquarie material was probably incorrectly identified.

It should be noted that all commercially produced *Melaleuca* oils derive from species belonging to *Spiciflorae*. *M. cajuputi* Powell (as well as certain closely related broad-leaved *Melaleucas* growing in the Indonesian archipelago) and the cineole-rich form *M. quinquenervia* (Cav.) S.T. Blake (once incorrectly named *M. viridiflora* Gaertn.) yield the medicinal oils of 'cajeput' and 'niaouli' respectively, whilst the fragrant nerolidol-rich form of the latter species has once been used for perfumery purposes. The terpinen-4-ol forms of *M. alternifolia* Cheel and *M. linariifolia* Am. yield oils with remarkable bactericidal properties (Penfold and Grant, 1926).

### RESULTS AND DISCUSSION

Analysis of the freshly extracted steam-volatile oils by means of capillary gas-liquid chromatography (GLC) and mass spectrometry (MS) has shown that the oils of all three species are almost entirely monoterpenoid and qualitatively quite similar (Table 1).

*M. armillaris*, a tall and densely leaved shrub of southeastern coastal Australia, commonly known as 'giant myrtle' yielded oils rich in 1,8-cineole (up to about 70%). Minor components included  $\alpha$ -pinene, limonene and  $\alpha$ -terpineol, whilst  $\alpha$ -phellandrene was present in trace amounts only.

*M. dissitiflora*, a shrub of central Australia, yielded somewhat more variable oils. Those obtained from foliage collected in the Davenport Ranges were invariably rich in 1,8-cineole and thus greatly resembled the oil of *M. armillaris*, whilst oils extracted from trees growing near Charles River in the vicinity of Alice Springs contained terpinen-4-ol as their main component with 1,8-cineole never exceeding 10%. It appears, therefore, that *M. dissitiflora* exists in two chemical forms characterized by 1,8-cineole and terpinen-4-ol respectively, a phenomenon previously encountered in the related species *M. alternifolia* and *M. linariifolia* (Penfold and Morrison, 1946; Penfold, Morrison and McKern, 1948; Davenport, Jones and Sutherland, 1949).

*M. trichostachya*, a widely distributed Australian inland species, yielded a leaf oil rich in  $\alpha$ -pinene and 1,8-cineole (52% and 30% respectively). Since only one sample of foliage was available for our study no conclusions can be drawn about the chemical variability of the oils of this species. The results reported by Baker and Smith (1910) on the oil from Gladstone suggest that compositional variation may be rather large.

From an economic point of view *M. armillaris* and particularly the terpinen-4-ol form of *M. dissitiflora* may be promising. The comparatively high 1,8-cineole content of the leaf oil of the former, its very low  $\alpha$ -phellandrene content (undetectable by the usual nitrite phellandrene test) as well as its vigorous regrowth habit could make *M. armillaris* an attractive alternative source of the medicinally useful 1,8-cineole. The consistently high terpinen-4-ol content of the Charles River population of *M. dissitiflora* (Table 2) may allow its oil to be used in the same way as that of *M. alternifolia* for medicinal as well as flavouring applications. Being, unlike *M. alternifolia* and *M. linariifolia*, an inland species it may be suitable for the establishment of plantations in the arid Australian outback.

### EXPERIMENTAL

Collection of Plant Material and Isolation of Volatile Oils.

Fresh foliage and terminal brachlets of *M.*

TABLE 1.

% Composition of Melaleuca Oils<sup>+</sup>

Peak	Compound	M. <u>armillaris</u>	M. <u>dissitiflora</u>		M. <u>trichostachya</u>
			Charles River	Davenport Ranges	
1*	$\alpha$ -thujene	0.1- 2.5	-	-	0.7
2*	$\alpha$ -pinene	5.0- 6.4	2.2-10.7	1.4- 2.0	50.0
3	camphene	tr.	tr.	-	-
4	$\beta$ -pinene	1.2- 1.6	0.4-14.7	0.7- 0.9	2.5
5	sabinene	0.2- 0.6	tr.- 0.9	tr.- 0.6	0.3
6	myrcene	2.1- 2.4	0.6- 1.3	0.5- 1.3	1.7
7	$\alpha$ -phellandrene	0.1- 0.2	tr.- 1.1	tr.	-
8	$\alpha$ -terpinene	0.1- 0.3	3.8-10.1	tr.- 1.5	0.1
9	limonene	6.3- 7.3	0.4- 1.3	5.3- 6.7	2.2
10	unknown	-	tr.- 0.9	tr.	-
11	1,8-cineole	58.7-69.0	1.5- 7.3	63.1-65.8	30.1
12	$\gamma$ -terpinene	0.3- 0.8	12.0-18.2	0.4- 5.8	0.5
13	p-cymene	tr.- 0.5	1.7-14.2	0.7- 2.1	0.1
14	terpinolene	0.1- 0.3	2.0- 3.8	3.1- 3.3	0.2
15	p, $\alpha$ -dimethylstyrene	-	tr.- 0.2	0.1- 0.3	0.1
16	unknown	tr.- 0.4	0.1- 0.6	tr.- 0.3	-
17	linalool	tr.- 0.5	tr.- 0.6	tr.- 0.2	-
18	sesquiterpene C <sub>15</sub> H <sub>24</sub>	-	0.2- 0.6	-	-
19	sesquiterpene C <sub>15</sub> H <sub>24</sub>	tr.- 0.2	0.7- 1.4	tr.- 0.2	0.3
20	unknown	tr.- 0.2	tr.- 0.2	tr.	0.6
21	unknown	-	-	-	0.6
22	$\beta$ -selinene	tr.- 0.9	-	-	1.6
23	terpinen-4-ol	0.7- 1.0	23.1-51.8	1.5- 6.6	1.4
24	aromadendrene	tr.	0.5- 0.7	-	-
25	trans- $\beta$ -terpineol	tr.- 0.2	-	tr.- 0.2	-
26	unknown	tr.- 0.3	tr.- 0.2	tr.- 0.3	0.2
27	neryl acetate	tr.	-	tr.- 0.2	0.2
28	monoterpenoid alcohol C <sub>10</sub> H <sub>18</sub> O	0.2- 1.4	0.1- 0.3	0.2- 2.6	0.2
29	C <sub>10</sub> H <sub>16</sub> O	tr.- 0.2	0.1- 0.4	0.1- 0.8	0.3
30	$\alpha$ -terpineol	7.5- 8.8	1.3- 2.7	4.4- 8.5	1.1
31	$\alpha$ -terpinyl acetate	tr.- 0.5	tr.	tr.- 0.1	tr.
32	sesquiterpene C <sub>15</sub> H <sub>24</sub>	-	-	tr.- 1.0	-
33	sesquiterpene C <sub>15</sub> H <sub>24</sub>	tr.- 0.2	-	-	0.5
34	piperitone	-	tr.- 0.2	tr.- 0.3	-
35	geranyl acetate	0.5- 1.3	tr.- 0.3	tr.	0.2
36	trans-piperitol	-	0.4- 1.0	tr.- 0.9	0.4
37	8-p-cymenol	0.1	-	tr.- 0.2	-
38	sesquiterpene C <sub>15</sub> H <sub>24</sub>	0.1- 1.0	-	-	-
39	geraniol	0.1- 0.5	0.1- 0.2	tr.- 0.5	0.5
40	trans-nerolidol	0.1	-	-	0.1
41	methyleugenol	-	-	tr.- 0.9	0.7
42	unknown	-	-	-	1.3
43	unknown	tr.- 0.1	-	-	0.2
44	unknown	-	-	tr.- 0.3	0.2
45	unknown	-	-	-	0.3
46	unknown	-	tr.	tr.- 0.2	0.2

\*these two compounds co-injected on the FFAP coated column but could be separated on a DC550 coated column. +tr.: <0.1%

TABLE 2.

Oil Composition of Charles River Population of  
M. dissitiflora

Tree no.	Terpinen-4-ol content (%)	1,8-cineole content (%)
1	51.8	2.1
2	46.3	1.3
3	38.6	1.8
4	39.5	1.5
5	37.7	1.7
6	35.1	1.5
7	23.1	7.3

TABLE 3.

Species	Locality	Oil Yield % V/W	$n_D^{20}$	$\alpha_D^{20}$	$d_{20}^{20/4}$
<u>M. armillaris</u>	Asquith and Berowra Hts. north of Sydney, N.S.W.	0.90	1.4612	+1.2 <sup>v</sup>	0.9093
		to 2.16	to 1.4634	to +3.8 <sup>v</sup>	to 0.9147
<u>M. dissitiflora</u>	Davenport Ranges, N.T.	1.88 <sup>*</sup>	1.4658	+0.4 <sup>v</sup>	0.9144
		to 2.18	to 1.4660	to +2.0 <sup>v</sup>	to 0.9190
	Charles River, N.T.	1.40 <sup>*</sup>	1.4630	+10.0 <sup>v</sup>	0.8903
		to 4.25	to 1.4807	to +14.8 <sup>v</sup>	to 0.9144
<u>M. trichostachya</u>	Hugh River, N.T.	1.28 <sup>*</sup>	1.4663	+19.8 <sup>v</sup>	0.8864

\* Yield based on weight of air-dried plant material.

*armillaris*, obtained from cultivated trees growing at Berowra Heights and Asquith, and similar but air-dried material of *M. dissitiflora*, collected at Elkedra and Bonney Well in the Davenport Ranges and at Charles River near Alice Springs, and of *M. trichostachya* from Hugh River west of Alice Springs, were steam-distilled as described previously (Lassak, 1979) to yield colourless to pale yellow oils (Table 3). Botanical voucher specimens are lodged at the Biological and Chemical Research Institute (*M. armillaris*) and at the Northern Territory Herbarium, Arid Zone Research Institute (*M. dissitiflora* and *M. trichostachya*).

#### Identification of Oil Components

Analytical GLC was conducted on a Perkin Elmer Sigma 2B chromatograph using a 50m by 0.2mm i.d. FFAP coated fused silica column with He as carrier gas. Individual runs were temperature programmed from 80° to 170° at 6°/min following an initial holding period of 9 min at 80°. Individual components were tentatively identified by their retention times and by co-injection with authentic compounds. A Perkin Elmer Sigma 10B Chromatography Data Station was used to determine percentage compositions.

GLC/MS were determined using Shimadzu GC6-AMP gas chromatograph equipped with a FFAP coated SCOT column (105m by 0.5 mm i.d.) or an OV 17 coated SCOT column (109m by 0.5 mm i.d.) interfaced to an AEI MS-1w mass spectrometer through an all-glass straight split with He as carrier gas. The gas chromatograph was programmed from 70° - 230° at 3°/min; the mass spectrometer operated at 70 eV with the ion source at 150°. Spectra were recorded and processed by a VG Digispec Display data system which produced standard bar graphs for direct comparison with published spectra.

The following compounds were isolated by fractional distillation of the oils and their identities confirmed by their infrared spectra:  $\alpha$ -pinene, 1,8-cineole and terpinen-4-ol; the presence of piperitone was confirmed by its isolation (neutral sulphite method) followed by conversion to its 2,4-DNP derivative.

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## Lake Dieri and its Pleistocene Environment of Sedimentation, South Australia

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**ABSTRACT.** Recent geological investigations have shown that the Oligocene Cordillo Surface (Wopfner, 1974) was deformed in mid Tertiary time into the Lake Eyre and Lake Frome structural basins separated by a positive tectonic divide. Sediments from late Tertiary to Holocene were deposited on both sides of the divide. Thus, Lake Eyre and Lake Frome had separate late Pleistocene ancestral lakes, and one large lake (Löffler and Sullivan, 1979) covering both structural basins, was unlikely to have occurred. It is proposed that the name Dieri should be preserved for the late Pleistocene ancestor of Lake Eyre, and the name Pilatapa could be used for the equivalent ancestor of Lake Frome.

The occurrence of fresh and saltwater fossils in Lake Dieri sediments has been regarded as evidence of cyclic climatic variation. It is now suggested that salinity layering may have occurred due to fresh riverwater entering upper layers and overflowing to the sea, and highly saline groundwater entering through the lake bottom to form highly saline, heavy bottom water.

### INTRODUCTION

Lake Eyre, to the northwest of the Flinders Range, and Lakes Frome, Callabonna, Blanche and Gregory, to the east and northeast (Fig. 1), are members of a family of contemporary ephemeral lakes in an arid environment. They developed during Holocene time from late Pleistocene ancestors which occupied the positions of the present lakes and extended beyond. The former lake which was the permanently-filled ancestor of present-day Lake Eyre, is known as Lake Dieri, the tribal name of Aborigines living in the vicinity. The history of the concept and naming of Lake Dieri has been reviewed by Löffler and Sullivan (1979).

The idea of a lake in a more pluvial or wetter environment, overflowing to the ocean and eventually drying up with the onset of aridity to become present-day Lake Eyre, appears to have been first suggested by Gregory (1906) and then by Howchin (1909). Fenner (1931) and David (1932) later suggested that the ancestral lake could have embraced Lakes Frome, Callabonna, Blanche and Gregory. Browne (1945) first recorded the name Lake Dieri, acknowledging that it had been suggested earlier by Sir Edgeworth David (pers. comm.) but unrecorded. The name has since been used by other authors including King (1956), Johns (1963), Löffler and Sullivan (1979) and Dulhunty (1982).

From the distribution of longitudinal sandridges and aligned transverse claypans, and interpretation of satellite imagery, Löffler and Sullivan (1979) suggested that Lake Dieri covered Lake Eyre, much of the southern Simpson Desert, the Tirari and Strzelecki Deserts and Lakes Frome, Callabonna, Blanche and Gregory. They also suggested that it might have existed over a long period of time extending back into the late Tertiary, and that it gradually diminished with many oscillations throughout Pleistocene time.

They mapped the northern and eastern boundaries of aligned pans as limits of Lake Dieri in those directions, but did not show any boundaries west of Lakes Frome and Callabonna, or south and west of Lake Eyre.

The purposes of this paper are

- (a) to support the general concept of late Pleistocene ancestral lakes, but to suggest that there were two main lacustrine areas of limited extent and duration rather than one large lake existing throughout Pleistocene time,
- (b) to show probable limits to the occurrence of late Pleistocene lakes west and southwest of Lakes Frome, Callabonna, Blanche and Gregory, and to the south and west of Lake Eyre, and
- (c) to suggest that salinity layering might have been an environmental factor in Lake Dieri contributing to simultaneous co-existence of fresh and saline conditions of sedimentation.

### EVOLUTION OF LAKE EYRE AND LAKE FROME DEPOSITIONAL REGIONS

Results of recent investigations bearing directly on Cainozoic geological history of the Lake Eyre and Lake Frome internal drainage system, have been recorded by Callen (1977), Callen and Tedford (1976), Jessup and Norris (1971), Löffler and Sullivan (1979), Wopfner, Callen and Harris (1974) and Wopfner and Twidale (1967).

From the foregoing recorded results, it is evident that the widespread deep subsidence, which formed the Great Artesian Basin and its Mesozoic sediments, came to a close in late Cretaceous and early Tertiary time with the deposition of

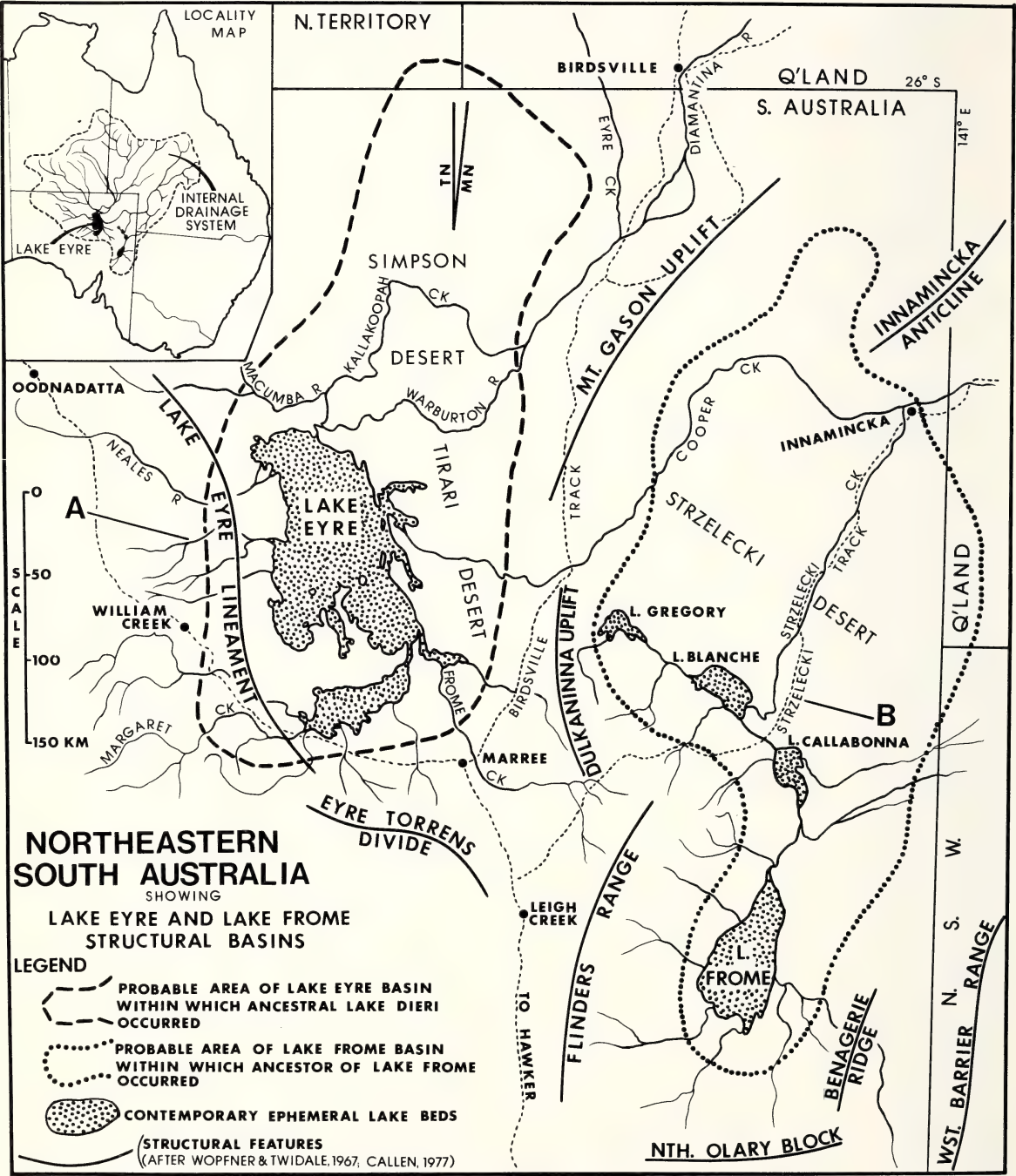


Fig. 1. Areas of structural basins within which late Pleistocene ancestors of Lake Eyre and Lake Frome could have occurred.

Palaeocene - Eocene Eyre Formation in central and southwestern areas of the basin. As it waned subsidence contracted to the southwest giving the basin and its sediments a very gentle tilt in that direction. This, together with mid Tertiary movements, provided the basic setting for subsequent Pleistocene development of the present-day Lake Eyre internal drainage system with its Lake Frome sub-basin.

The deposition of the Eyre Formation was followed by a long non-depositional period in Oligocene time during which the Cordillo Surface (Wopfner, 1974) formed with its encrustation of early Tertiary silcrete. During late Oligocene or early Miocene time the surface was deformed in the southwestern Great Artesian Basin, and subdivided into two large structural depressions which became separate depositional regions after mid to late Miocene time. One of these covered Lake Eyre, the southern Simpson Desert and Tirari Desert, and the other covered the Lake Frome and Strzelecki Desert region including Lakes Callabonna, Blanche and Gregory. They are referred to as the Lake Eyre Basin and Lake Frome Basin. The two were separated by a zone of positive tectonic features running generally north from the Flinders Range along the Dulkaninna and Mt. Gason Uplifts to the vicinity of Birdsville (Figs 1 & 2). The Birdsville Track now follows the more elevated and less sandy country along the positive tectonic zone.

From about mid or late Miocene to early Pliocene the two depressions became depositional. The Namba Formation was deposited in the Lake Frome Basin and the Etadunna Formation in the Lake Eyre Basin. Then, following another non-depositional interval in Pliocene time, the late Pliocene - early Pleistocene Milliyera Formation accumulated in the Lake Frome Basin. Equivalent early Pleistocene sediments have not yet been fully investigated in the Lake Eyre Basin, but they are almost certainly present to a greater or less extent (Stirton, Tedford and Miller, 1961). Another non-depositional period would seem to have occurred about mid Pleistocene time during which the Flinders Range continued to rise (Callen, 1977) and post Etadunna movement occurred along the tectonic divide between the two basins in each of which further depression occurred.

Then, as a result of a wetter climatic phase (Bowler, 1978) in late Pleistocene time, more or less permanently filled lakes developed on both sides of the tectonic divide, which would appear to have risen to no more than 40 m above the beds of the two lakes in some places, but over 200 m at others. They were separate lakes but if filled to over about 40 m deep, then water could have flowed between them through a relatively narrow channel between the south end of the Mt. Gason Uplift and the north end of the Dulkaninna Uplift, where Cooper Creek now flows from the Strzelecki Desert to the Tirari Desert (Fig. 1).

In the late Pleistocene lake of the Lake Frome Basin the Eurinilla Formation was deposited disconformably upon earlier Pleistocene sediments. In the Lake Eyre Basin a widespread lake developed in which late Pleistocene sediments accumulated

disconformably upon early Pleistocene beds in some places, and unconformably on Tertiary, Mesozoic and metamorphic basement rocks beyond the areas of early Pleistocene sediments (King, 1956; Wopfner and Twidale, 1967; Callen and Tedford, 1976). Deposition then ceased in both basins as they dried up with the onset of aridity towards the close of Pleistocene time. After some deflation during intense aridity, further depression and gentle folding in the Lake Eyre Basin and a return to a less arid phase with a rise in watertable (Dulhunty, 1982), Holocene sedimentation commenced on both sides of the dividing ridge (Fig. 2). The Coonarbine Formation was deposited in Lake Frome, and equivalent sediments, as yet unnamed, commenced deposition in Lake Eyre (Dulhunty, 1982).

#### LAKE DIERI, ANCESTOR OF LAKE EYRE

In view of the foregoing relations between tectonic and depositional histories in the Lake Eyre and Lake Frome Basins, the following suggestions are offered:

1. The idea of Lake Dieri being one large lake covering both basins throughout part or all of Pleistocene time, must now be modified to a concept of early and late Pleistocene lakes separated in time by a mid Pleistocene non-depositional interval, and occurring in each of two basins separated geographically by a structural high.

2. With respect to the work of early Australian geologists, the name Lake Dieri should be preserved and used as the name of the late Pleistocene ancestral lake in the Lake Eyre Basin, from which present-day Lake Eyre descended.

If a name is required for the late Pleistocene lake in the Lake Frome Basin, which was the ancestor of Lake Frome and in which the Coonarbine Formation was deposited, then the tribal name Pilatapa of Aboriginal people previously living in the vicinity of Lakes Frome and Callabonna, could well be used (Dr. L. A. Hercus, pers. comm.; Tindale, 1974).

#### LATE PLEISTOCENE ENVIRONMENT OF SEDIMENTATION IN LAKE DIERI

Lake Dieri received drainage from a catchment area very similar to that of the present-day Lake Eyre internal drainage system. It occupied the present position of Lake Eyre, and it is believed by the author and others including Gregory (1906), Johns (1963) and Callen (1977) to have had an outlet to the sea. In addition to riverwater, Lake Dieri received large volumes of groundwater as its bed would have been the sump, or focal area, for movement of groundwater in the whole of the drainage system. Owing to low surface level, poor drainage and cyclic aridity in the central Great Artesian Basin area in Tertiary and early Pleistocene times, and the great thickness of underlying Cretaceous marine sediments that had never been appreciably elevated above sealevel, the groundwater must have been very saline around Lake Dieri. Thus its inflow must have been an important factor influencing salinity of the lakewater.

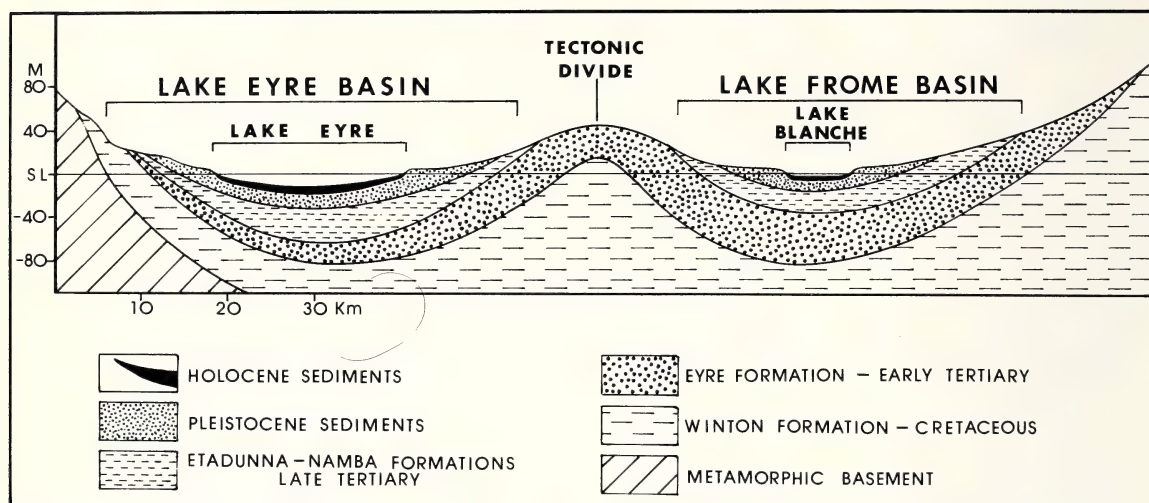


Fig. 2. Section A-B across Fig. 1, showing relations between structural development and stratigraphy.

Sediments deposited in the southwestern area of Lake Dieri now outcrop in cliffs and steep shoreline slopes along the southern shores of Lake Eyre North, between Willow Head and Price peninsula (King, 1956; Johns, 1963). Outcrops up to 13 m thick were measured by the author along the southern shores of Madigan Gulf, and at Shelly Island. At least 4 m appeared to have been removed by weathering and erosion, making a probably minimum original thickness of some 17 m. King (1956) described a section of almost 10 m in the same vicinity.

Lake Dieri sediments have yielded both freshwater and brackish to saltwater fossils, including *Coxiella gilesi*, foraminifera, fish bones, *Diprotodon* and crocodile remains (Stirton et al., 1961; Wopfner and Twidale, 1967), *Chara* and ostracods (King, 1956; Johns, 1963). Consequently the environment of the lake has been regarded variously in the past as either fresh, brackish to salt, or as alternating within such limits with cyclic variations in climatic phases.

After recent field observations, consideration of environmental factors and stratigraphical relations, as well as the probability of a wetter climate with lower evaporation and higher watertable levels in late Pleistocene time (Bowler, 1978; Dulhunty, 1982), it is now suggested that Lake Dieri might have been a permanently-filled lake during a time interval of the order of 20,000 to 45,000 years b.p. Also that freshwater and saline environments of sedimentation might have co-existed as a consequence of salinity layering. This could have developed by continuous addition of fresh riverwater from the north and northeast to upper layers of lakewater and their escape to the south into the sea, concurrently with subterranean inflow of saline groundwater, through the lake bottom, into lower layers of bottom water. Such circumstances could have supported freshwater

organisms and condition in light upper layers and along shorelines, and also, at the same time, saltwater organisms and conditions including deposition of gypsum in heavy bottom layers. As a consequence, simultaneous deposition of fresh and saline sediments could have occurred. Also a mixed-facies sediment could have formed where freshwater debris sank and became entombed in the saline environment.

An example of salinity layering and co-existence of relatively fresh and highly saline environments developed in Lake Eyre during the 1974 filling (Dulhunty, 1977; 1982). If the temporary wetter climate that occurred in the Lake Eyre region during almost 7 years of the filling had prevailed as it did in Lake Dieri time, inflow of riverwater would have continued, and shoreline and upper water would have become virtually fresh, and continued to co-exist with the saline bottom water. However, though the 1974 filling was only transient, it could be regarded as a very short-lived reversion, possibly approximating to the late Pleistocene climate of the Lake Dieri environment.

The possible development of salinity layering in Lake Dieri, by subterranean inflow of highly saline groundwater into bottom waters, would appear to be very similar to hydrological processes operating in present-day lakes in different parts of the world (D. K. Hobday, pers. comm.; Eugster and Hardie, 1978; Hardie, 1968; Hardie, Smoot and Eugster, 1978).

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## Silcretes in the Cobar Area, New South Wales

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**ABSTRACT.** A recent, detailed geological survey of the Cobar area in central-western New South Wales has disclosed areas of silcrete development. In hand specimen and in chemical analyses, these silcretes closely resemble previously known occurrences found west of Cobar (Dolo Hills, N.S.W.) and northwest of Cobar (Tibooburra area, N.S.W. and adjacent area in southwest Queensland). However, on outcrop scale Cobar silcretes differ from those further west in that they form only localized occurrences, rather than extensive sheets. Localities, descriptions in hand specimen and thin section, and chemical analyses are given to document these silcrete occurrences. Although Wasson et al. (1979) have rightly questioned the earlier report by Dury (1966) of silcrete occurrences around Cobar, the new data presented here enable the Cobar area to be retained as a silcrete locality.

### INTRODUCTION

The map of Stephens (1971) showing the distribution of silcretes in Australia would suggest that silcretes should be found in the Cobar area of New South Wales (Fig.1, inset). Dury (1966) reported finding what he described as silcretes in this area, but Wasson et al. (1979) have rightly indicated that the materials described by Dury are not silcrete in the generally accepted definition.

In their concluding comments, Wasson et al. (1979, p 155) stated "... it is necessary to question the validity of any aspect of the geomorphic history of the Cobar area dependent upon the recognition of silcrete ...". Lest this sentence be construed to imply that silcrete does not occur in the Cobar area, this present note documents several such occurrences.

### TERMINOLOGY

There is no hard and fast definition of silcrete. There is a general consensus of opinion in the papers in "Silcrete in Australia" (Langford-Smith, 1978), that silcrete is a hard, indurated rock, composed mainly of quartz grains, occasionally with quartz "eyes", and cemented by fine-grained silica. Silcrete has a conchoidal fracture, due to equal hardness of framework grains and cement. Foreign minerals are either very rare and/or extremely small. Commonly associated with these easily recognized silcretes may be rocks showing secondary silica enrichment. These rocks are softer and break more irregularly than silcrete. They may also contain more evidence of the precursor rock-type.

### SILCRETES IN THE COBAR AREA

#### Hand Specimen Description

Silcretes in the Cobar area vary in colour from white through yellow to red, and there is some development of iron-stained rinds. True

silcretes are hard and break smoothly with a conchoidal fracture. Quartz "eyes" are present in some cases. Intermixed on outcrop scale with these easily recognized silcretes are white to red coloured rocks showing secondary silicification. These break irregularly, reflecting irregular hardening, and may display linear, rod-shaped structures similar to those of Wopfner (1978, Fig.10). Quartz clasts may be present in these rocks as well as in the true silcretes. Baker (1978) noted that silcrete may be commonly associated with ferricrete.

#### Distribution and Nature of Occurrences

Silcrete bodies found in the Cobar area during the course of a regional mapping programme by the Geological Survey of New South Wales are shown in figure 1. Most of the silcretes occur in areas underlain by sediments of the Early Devonian Cobar Supergroup, with only limited development on areas underlain by basement rocks. These two units generally form subdued to poor outcrop and silcretes occur at a range of topographic heights, not necessarily on high hills or peaks (Fig.1). In areas of the Cobar Supergroup high points are generally underlain by sandstone-rich lithologies, only some of which are silicified. In these cases, silcrete forms a capping and may also extend patchily down the hill slope. On other high points, alteration is restricted to the formation of minor weathering skins (compare data on the Biddabirra Hill site - BH Fig. 1 - between Dury 1966 and Wasson et al. 1979).

The absence of silcrete from rocks of the Mulga Downs Group overlying the Cobar Supergroup is surprising. Despite the large amount of sandstone in the sequence, which has localized the formation of cuestas occupying some of the highest country around Cobar, (near) surface alteration is restricted to the formation of weathering skins, caused by the removal of iron oxides from the rock (compare data on the

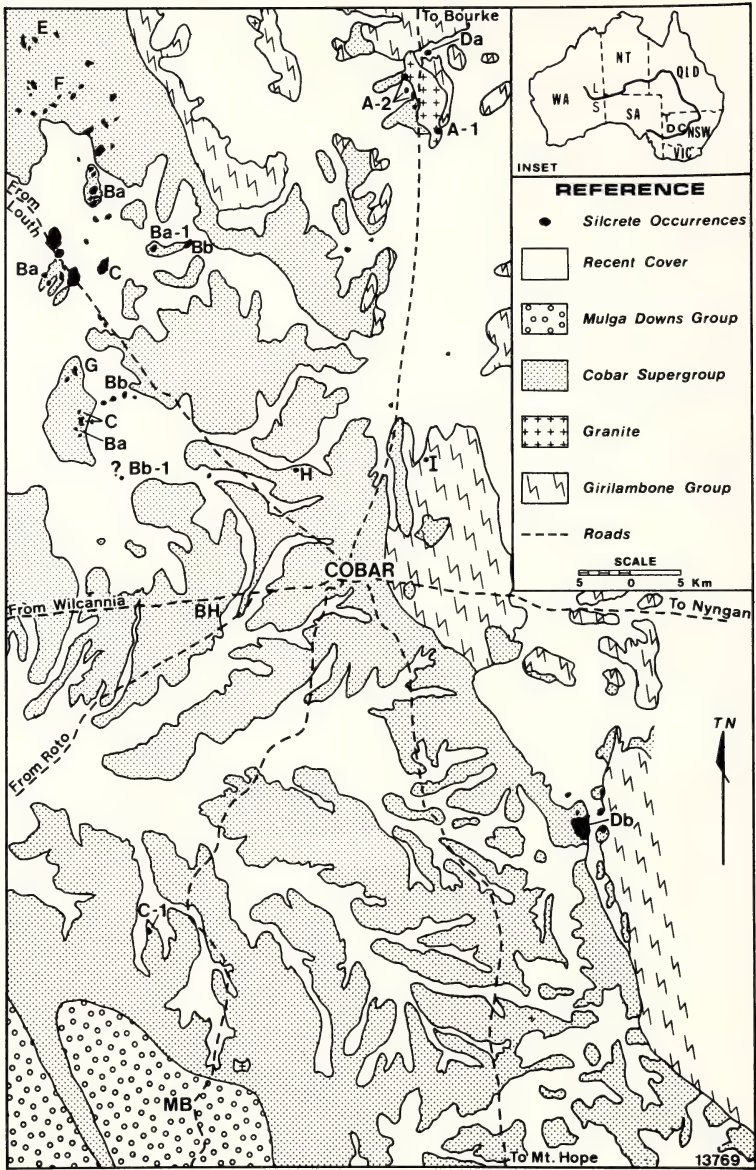


Fig. 1 Inset - Australia showing location of Cobar (C), Dolo Hills (D) and Tibooburra(T). L/S line from Stephens (1971). - silcrete inside the line, laterite outside the line.

Main Figure - Simplified geology of the Cobar area, modified from Baker (1977), Felton (in press),Glen et al. (in press). Sizes of silcrete bodies have been exaggerated. Approximate topographic heights of silcrete bodies from base geological maps:

A-1 200m, A-2 200<sup>+</sup>m, Ba-1 200<sup>+</sup>m, Bb< 200m, Ba (NW) ~ 200m, Bb-1 220m, C-1 < 200m, C ?200m (mid north), 200<sup>-</sup>m (northwest), Da 220m, Db 260m, E < 240m, F ~ 200 m, G 200m, H 240 m, I 220 m, BH (Biddabirra Hill) peak 270m, BM (Mt Buckambool Peak) 405m.

Mt Buckambool site - MB Fig. 1 - between Dury 1966 and Wasson et al. 1979).

The silcretes we have seen in the Cobar area do not form extensive sheets such as those described from S.A. by Wopfner (1978) and from the NW corner of NSW by Watts (1978). Rather, individual outcrops are generally small (tens to a hundred square metres in area) and most of the silcrete occurrences in figure 1 consist of individual boulders and pebbles separated by, and lying in, recent fine-grained eluvium. At locality A-1 (see below), outcrop is more continuous and silcrete forms relics of a thin crust on granite. Around the northwestern part of the Louth Rd in fig.1, silcrete boulders, generally covered by eluvium, probably form part of a partly buried surface. It would thus appear, that what we see at Cobar may be relics of more extensive silcrete deposits, that have either been partly buried and/or partly broken up and removed. The absence of a widespread sheet probably accounts for the non recognition of silcrete in the past.

#### Silcrete Associations

As outlined above, silcrete generally occurs as variably-sized fragments in eluvium. However, from relations in some areas, it is possible to categorize silcrete occurrences into four types, based on their lithological relationship.

##### A. Silcrete on basement granite

Baker (1977, 1978) first noted and mapped occurrences of silcrete on the basement Tinderra Granite in the northeast part of the area in figure 1. Relations are probably best preserved at locality A-1 (Fig.1) where blocks of silcrete up to 0.3 m thick lie on poorly exposed weathered granite. Silcretes around locality A-2 probably also lie on granite subcrop. However, they also lie near sediments and the underlying lithology is not known with certainty.

##### B. Silcrete on the Cobar Supergroup

Two lines of evidence suggest that many silcretes in the northern part of the area are localized on sandstone-rich zones within the Cobar Supergroup.

The first line of evidence consists of silcrete on hill summits where it overlies marker sandstone-rich zones of the Cobar Supergroup which outcrop further down the hill slope (Ba, Ba-1 Fig.1). Silcrete here varies from boulders and pebbles in eluvium to iron-stained, fractured sheets of small outcrop (tens of square metres) up to 1m or so thick. In the second line of evidence, silcrete outcrop in slightly elevated areas lies along strike from sandstone zones in the Cobar Supergroup. Silcrete here generally consists of loose material, or as small fractured outcrops (Bb, ?Bb-1, Fig.1).

##### C. Silcrete on Cainozoic Conglomerate

The presence of Cainozoic conglomerates in the Cobar district (mainly south and east of, or towards the south of, Fig.1) has been recorded

in mapping by the New South Wales Geological Survey. The presence of similar conglomerates in the north-western part of the area in figure 1 is suggested by the local existence of a thin veneer of rounded pebbles of vein quartz and iron-stained sandstone freed by erosion, and by blocks of conglomerate containing clasts of vein quartz and sandstone in an iron-rich matrix. Most of these conglomerates show secondary silicification and some may be classified as true silcretes (C, Fig.1).

##### D. Silcrete on Pallid Zones

In two areas - locality Da at a breakaway near Tinderra Tank (Baker 1977) and locality Db at a quarry near Rookery Homestead (Brown 1976) - silcretes are underlain by a pallid zone. Relations are best described from the second site (Fig.2). Here rubbly silcrete at the surface passes down through 2 m of crudely fractured, silicified rock into a pallid zone which consists of quartz and kaolinite with minor illite and smectite (E. Slansky, pers. comm.). These relations are similar to those described by Wopfner (1978), although in neither of the localities is the material below the pallid zone exposed.

#### Thin Section Descriptions

Silcrete samples were collected for petrographic examination from several of the localities shown in figure 1. Typical ones are described here. Silcrete developed from granite at locality A-1 shows typical "terrazzo" textures of Smale (1973), with irregular shaped quartz grains in a uniform dark matrix. (Fig. 3a). Silcrete overlying sandstone at locality Ba-1 is similar (Fig.3b). It shows embayed and half-rounded to angular quartz grains in a cloudy-brown matrix containing a mass of fine shards. Of interest is the presence of accessory zircon and tourmaline inherited from the host rock. A thin section of silcrete from locality C-1 (possible developed on Cainozoic conglomerate) shows quartz grains less irregular and more round than described above (Fig.3c). Nor is the matrix as uniform, consisting in different areas of opaque material and very fine-grained quartz crystals.

#### Chemical Analyses (Table 1)

Chemical analyses of four silcretes from the Cobar area were carried out by X-ray fluorescence spectrometry (method of Hutton and Elliott, 1980). Table 1 shows that these Cobar silcretes are similar to silcretes from the Dolo Hills, about 220 km to the west, reported by Hutton et al. (1978), and from Tiboburra silcretes, about 420 km to the northwest, reported by Hutton et al. (1978). They are also similar to the average composition of 63 silcretes reported by Watts (1977) from northwestern New South Wales and southwestern Queensland.

Cobar silcretes have the usual low values of most elements except those associated with minerals that are resistant to weathering e.g. silicon, titanium and zirconium. The average of 0.95% Ti and 0.033% Zr for the four Cobar samples (Table 1) are both twice that of the average crustal abundance, namely 0.44% Ti and 0.016% Zr (Mason 1966).



Fig. 2 Silcrete occurrence at locality Db, exposed in quarry face. Rubble silcrete at surface overlies crudely columnar silcrete and silicified rock which passes down into pallid zone of quartz + clay minerals. Columnar silcrete about 2m thick.

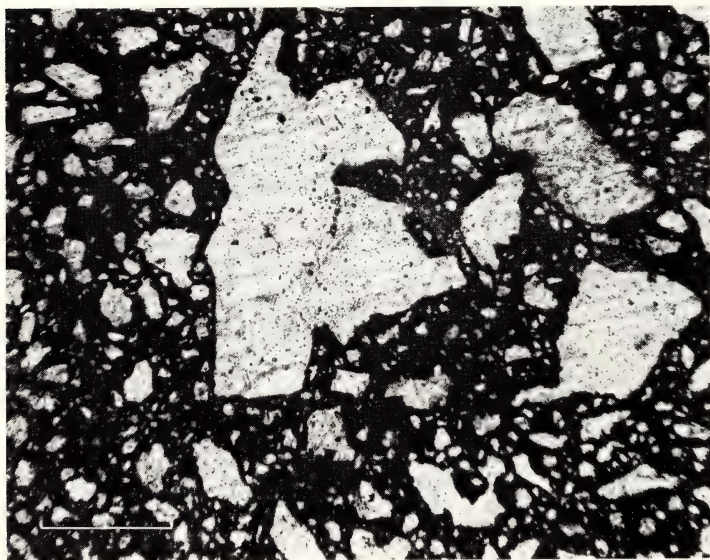


Fig. 3a Thin Section photograph of silcretes. Good "terrazzo" texture from locality A-1. Angular to semi-rounded and embayed quartz grains in an opaque matrix. Cross nicols. Bar scale 5 mm.

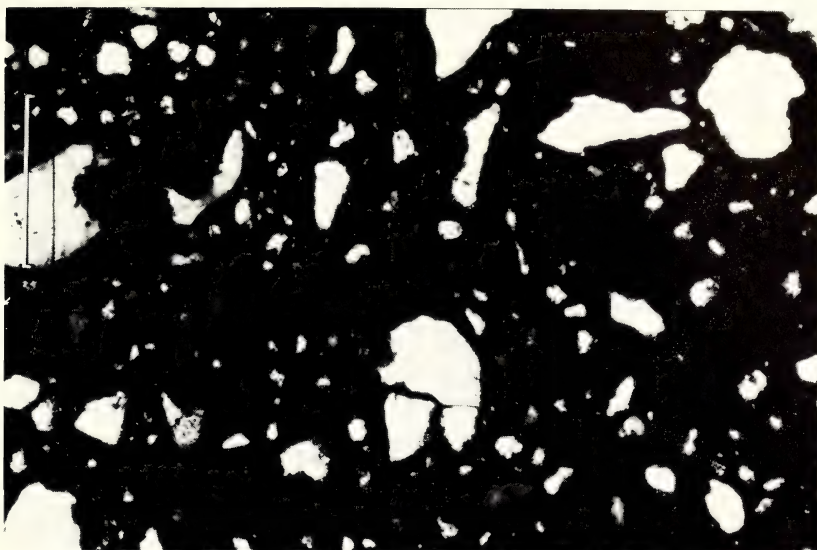


Fig. 3b Thin Section photograph of silcretes. Good "terrazzo" texture from locality Ba-1. Corroded and embayed quartz grains in an opaque matrix. Cross nicols. Bar scale 0.25 mm.

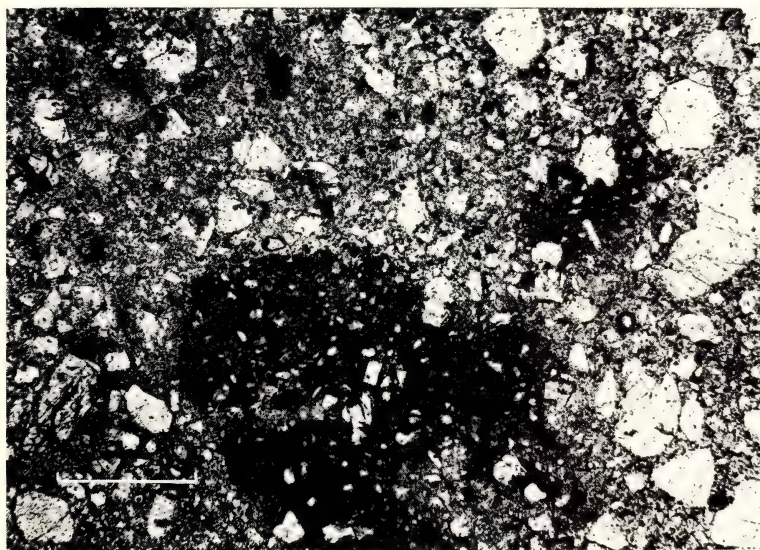


Fig. 3c Thin Section photograph of silcretes. Silcrete from locality C-1, see text for description. Cross nicols. Bar scale 5mm.

Table 1: Analyses of Cobar silcretes and comparison with other silcretes in far western N.S.W. and southwestern QLD

Locality	COBAR SILCRETES				OTHER SILCRETES			
	A-1	A-2	Bb-1	C-1	Dolo Hills <sup>1</sup>	Tibooburra 529 <sup>1</sup>	Tibooburra 531A <sup>1</sup>	Av. of 63 from SW QLD and NW N.S.W. <sup>2</sup>
Element								
Mg, %	0.01	0.01	0.01	0.01	0.11	0.03	0.09	0.04
Al, %	0.28	0.18	0.12	0.06	0.17	0.11	0.23	0.24
Si, %	46	45	46	46	47	46	46	45.2
P, %	0.01	0.01	0.01	0.01	0.1	0.02	0.02	-
K, %	0.02	0.03	0.06	0.03	0.03	0.01	0.01	0.03
Ca, %	0.02	0.02	0.02	0.02	0.21	0.02	0.04	0.06
Ti, %	0.7	1.1	0.6	1.4	1.4	0.7	0.9	0.88
Fe total, %	0.02	0.07	0.1	0.1	0.5	0.7	0.6	0.12
Zr, %	0.022	0.031	0.018	0.059	0.055	0.015	0.069	-
Ti/Zr	32	35	33	24	25	47	13	-

1. from Hutton et al (1978)

2. from Watts (1977)

## CONCLUSIONS

Although Wasson et al. (1979) pointed out that Dury's (1966) "silcretes" would not be called such today, their own paper should not be taken to deny the presence of true silcretes in the Cobar area. The samples described above are lithologically (both in hand specimen and in thin section) and chemically similar to silcretes described from further west and northwest in New South Wales and adjacent areas in Queensland.

Cobar silcrete is characterized by the dominance of silica minerals. Titanium minerals are also present, as indicated by chemical analyses and are generally fine-grained. Minerals containing aluminium are absent. In the literature, silcretes are associated with highly weathered profiles, with highly weathered sediments, such as the early Tertiary Eyre Formation, with quartz rich sandstones, and with granite (Wopfner 1978, Senior 1978). Similar associations occur at Cobar, with the addition of silcrete developed on Cainozoic gravels. Table 1 shows a marked chemical similarity of silcrete developed from different rock types. However, the different size ranges of quartz clasts in different silcretes help to differentiate those formed from fine-grained sandstone from those formed from coarser-grained conglomerate or granite. In/near situ development of silcrete is therefore suggested. Formation of the Cobar silcretes at different topographic heights (Fig.1) is not consistent with Dury's (1966) concept of a single pediplained surface.

## ACKNOWLEDGEMENTS

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## Basement/Cover Relations and a Silurian, I-Type Intrusive from the Cobar Lucknow Area, Cobar, New South Wales

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**ABSTRACT.** In the Cobar Lucknow area, 10km NE of Cobar in central western New South Wales, the Wild Wave Granodiorite is intrusive into the Cambro-Ordovician Girilambone Group and is nonconformably overlain by fossiliferous rocks belonging to the Meryula Formation of the Early Devonian Cobar Supergroup. A biotite Rb/Sr age from the granodiorite is  $418 \pm 2$  Ma [Middle-Late Silurian]. This date is similar to other biotite Rb/Sr ages obtained from other granitoids in the Girilambone - Wagga Anticlinorial Zone. The Wild Wave Granodiorite has a low initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of  $0.7051 \pm 0.002$  and is to date the only Silurian I-type granitoid recognised north of the Lachlan River in the Girilambone-Wagga Anticlinorial Zone. Other bodies - the Thule and Erimeran Granites, the Nymagee Igneous Complex, and possibly the Tinderra Granite - are all S-type. From the low initial ratios and the range of Rb/Sr ratios of possible source rock compositions, the source of the Wild Wave Granodiorite is inferred to be from mafic rocks in the lower crust.

### INTRODUCTION

Rocks around the town of Cobar in central western New South Wales consist of a cover sequence, the Early Devonian Cobar Supergroup, and a basement sequence comprising the Cambro-Ordovician Girilambone Group and intrusive Silurian granitoids (Pogson & Felton, 1978). Although relations between basement and cover are well understood on a regional scale there are very few individual localities where unconformable or nonconformable relations can be clearly demonstrated.

Diamond drilling at the Cobar Lucknow Prospect, 10km NE of Cobar, by Getty Oil Development Co in 1980 has enabled us to clarify relations at such a previously, poorly understood site. We can now document the presence here of a Silurian I-type granitoid — the first found north of the Lachlan River in Girilambone - Wagga Anticlinorial Zone of Scheibner (1976) — which is nonconformably overlain by a fossiliferous cover sequence belonging to the Cobar Supergroup.

### REGIONAL GEOLOGY

Relations north of Cobar township are shown in figure 1 (inset). The north/south trending Rookery Fault (RF in figure 1) marks the eastern margin of the Cobar Basin. Rocks to the west are turbiditic in character (Glen, 1982) and belong to the Nurri and Amphitheatre Groups of the Cobar Supergroup. Rocks east of this fault consist not only of basement rocks, low-grade, dominantly turbiditic Ballast beds of the Girilambone Group, but also of infolded outliers of the shelfal Meryula Formation of the Cobar Supergroup (see below) which is equivalent in time to the Nurri Group and lower part of the Amphitheatre Group. Northeast trending linears of the Cobar-Inglewood Lineament (Scheibner, 1973) bracket the Cobar area and are shown in Fig.1 (inset).

### GENERAL GEOLOGY OF THE COBAR LUCKNOW AREA

The geology of the Cobar Lucknow area is dominated by an outlier of the Meryula Formation, which is faulted on its eastern side against low grade Ballast beds of the Girilambone Group (Fig.1). The lack of solid outcrop in the area, and the restriction of exposures to chips and rubble lying on the surface, account for the lack of structural data in figure 1, and also explain differences in previous interpretations. The presence of cover rocks in the Cobar Lucknow area was first noted by Andrews (1913, p 183) and subsequently by Sullivan (1950) and Rayner (1969). Baker (1977, 1978) more recently mapped the outlier as undifferentiated Cobar Group (now Cobar Supergroup), noted its faulted eastern margin, and established a sequence of conglomerate passing up into fossiliferous mudrock. Subsequent work further south established the presence of several similar outliers to which the name Meryula Formation was given, superseding, in part, the old name Mallee Tank Beds (Pogson & Felton, 1978). Here, we extend the term Meryula Formation to the outlier in the Cobar Lucknow area.

The boundaries of the outlier in figure 1 are based on mapping by Lewington (1980), who extended westwards the area of cover rocks recognized by Baker (1977). At the eastern edge of the outlier, conglomerate at the base of the Meryula Formation is faulted against rocks of the Girilambone Group (both unsilicified and silicified) and also occurs in fault slivers surrounded by silicified rocks of the Girilambone Group. On the western side, the outlier is separated by a thin strip of Girilambone Group from another dominantly mudrock cover sequence centred on Maryantha Homestead. Baker correlated this sequence with the Chesney Formation. However, while not being able to rule out this correlation, we suspect that this second outlier may also consist of Meryula Formation, and show it as such in Fig. 1.

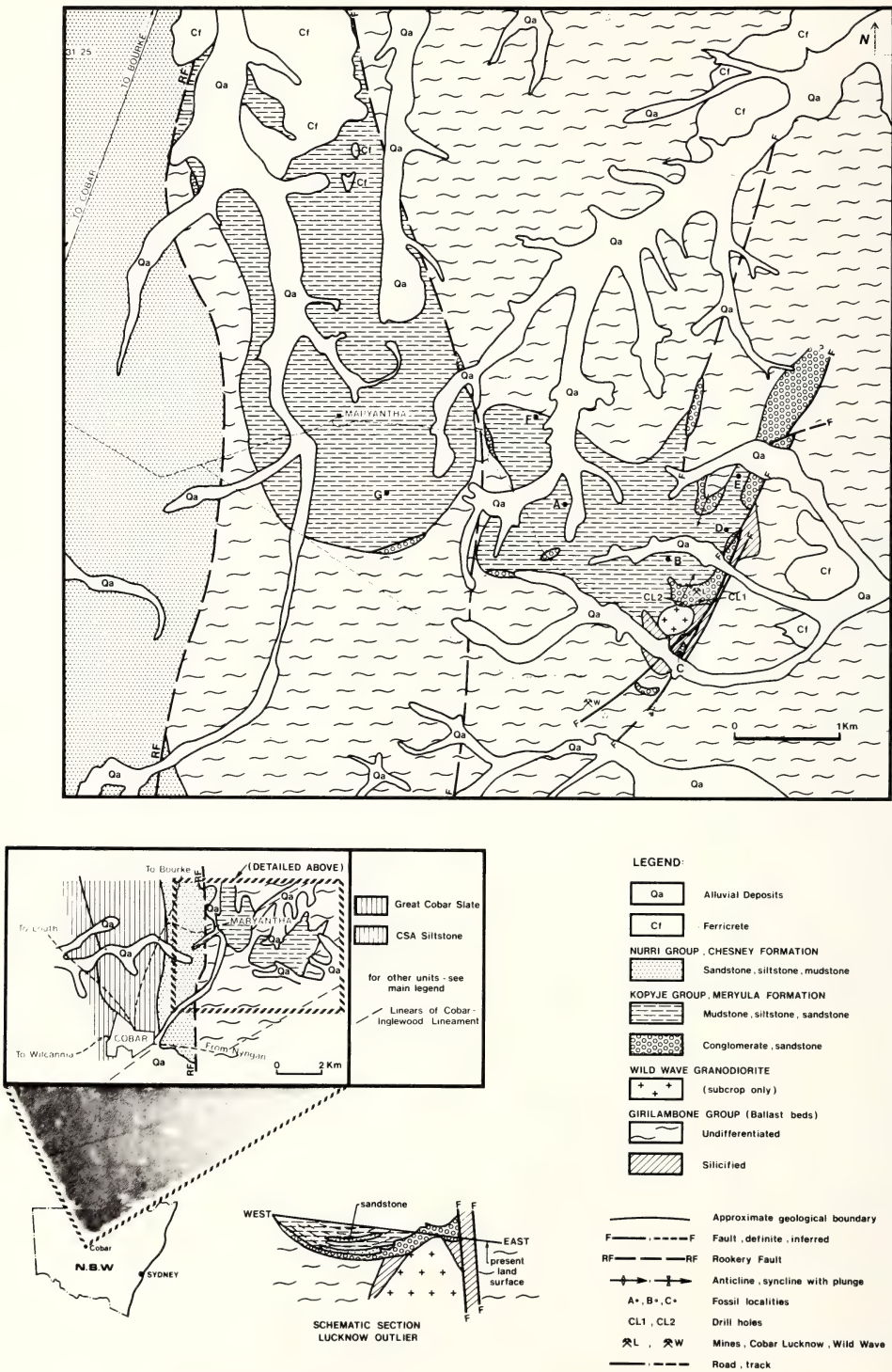


FIG. 1 Locality Map (inset) and Map of the Cobar Lucknow Area, showing location of the Wild Wave Granodiorite. Schematic cross section also shown.

Two diamond drill holes sunk near the Cobar Lucknow group of shafts by Getty Oil Development Co in 1980 to test co-incident aeromagnetic, gravity, I.P. and soil geochemical anomalies, penetrated fresh granodiorite.

Presence of fresh granodiorite in drill core explains weathered samples on the dump of the main Cobar Lucknow shaft, first noted by Mulholland (pers. comm. to Sullivan, 1950). Both Sullivan (1950) and Rayner (1969) inferred the presence of subsurface granite in this area, Rayner calling it the Wild Wave Granite, which we now amend to Wild Wave Granodiorite. Baker (1978), however, noted the presence of cobble-size fragments of weathered granite and wondered whether they merely indicated the presence of granite conglomerate. As will be described below, both views are correct.

#### DESCRIPTION OF GEOLOGICAL UNITS

##### Girilambone Group (Ballast beds)

Lithologically, the unit consists of micaceous sandstones, cleaved mudstones and discontinuous chert beds. Some fragments of sandstone contain planar and cross lamination. Bands of en echelon quartzite lenses, especially west of the Cobar Lucknow shafts, may reflect shear zones. Around the shafts themselves, sandstones are silicified in a 100m wide zone which fringes both the southern and eastern sides of the granodiorite.

##### Wild Wave Granodiorite

The granodiorite does not outcrop, but is concealed beneath recent cover and Devonian sediments. The inferred subcrop of this granodiorite, shown in figure 1, is based on drill intersections coupled with aeromagnetic and gravity anomalies. The rock is generally grey in colour, medium grained and massive with no obvious mineral orientation. Samples taken from three sections of granodiorite in hole CL1-G1 (100.00-160.85 m), G2 (108.65-199.00 m), G3 (228.5-228.9 m)-are dominated by quartz, subhedral plagioclase well twinned and zoned, interstitial K-feldspar, some microperthite, hornblende and biotite. Accessory minerals include apatite, magnetite and zircon. Biotite and hornblende occur as discrete crystals (2-4mm), commonly poikilitic, and also as intergrowths with biotite replacing hornblende. Alteration minerals consist of chlorite after biotite, epidote, sphene and carbonate from hornblende, and minor "sericite" after feldspar (see Appendix 1). The aeromagnetic anomaly of 85g over the pluton confirms the presence of moderate amounts of magnetite. Talc and chlorite-filled fractures are also common. Cross-cutting veins of calcite also contain small amounts of pyrite, pyrrhotite, galena and chalcopyrite. These sulphides are presumably responsible for the IP and geochemical anomalies identified during the early exploration phase.

Table 1 lists the chemical compositions of samples G1, G2 and G3. The analyses show a restricted range of silica around 64 percent and are reasonably high in  $K_2O$ , reflecting high

modal biotite. Sr values are high, a characteristic of the shoshonite I-type granitoids e.g. the Moonbi Plutonic Suite (Shaw & Flood, 1981), and are much higher than the I-type plutons of the Berridale Batholith (White et al, 1977).

The Wild Wave Granodiorite has distinctive I-type characteristics of Chappell & White (1974) and is unlike the A-type granitoids (Collins et al, 1982) which are characterised by much higher  $SiO_2$  and greater abundances of the highly charged cations such as Y and Zr.

##### Meryula Formation

The basal unit recognized in this formation in the Cobar Lucknow area is a conglomerate which outcrops generally only around the margins of the outlier (Fig.1). Maximum outcrop width of the conglomerate occurs along the eastern side of the outlier, against the bounding faults, and the conglomerate was probably deposited as a continuous sheet, now partially removed by erosion, from north of the Cobar Lucknow group of shafts to south of the Woolshed. From this part of the outlier, the conglomerate thins to the west, where it is restricted to minor lenses only. Around the Cobar Lucknow group of shafts, data obtained from the two drill holes and also from a partial descent of the main shaft indicate that conglomerate overlies a 20-50m thick zone of weathered granite. The boundary between the two is difficult to pick. Conglomerate up to 50m thick, contains pebble to cobble-size fragments of chert, siltstone, feldspar, quartz and granodiorite. Towards the top of the main Cobar Lucknow shaft, beds of conglomerate alternating with beds of arkosic sandstone dip at low angles ( $15^{\circ}$ - $20^{\circ}$ ) off the granodiorite to the northeast.

Elsewhere in the outlier, basal conglomerate passes upwards into a mudrock sequence which contains beds of subolithic arenite, up to 1m thick. Sandstones vary from massive to planar and cross laminated. Baker (1978, p35) reported a typical composition as 80% quartz grains with detrital muscovite in a groundmass consisting of quartz plus "sericite". Mudrocks weather to purple or yellow-brown in colour and outcrop badly. They are poorly cleaved.

Fossils have been found from five localities in the outlier. Those reported by Baker (1978), (Fig.1, locality B), include various brachiopods and corals indicative of an Early Devonian age (Sherwin, 1974). Other fossils include crinoid stems (locality C), trilobites and brachiopods (locality D) of an age near the Siluro-Devonian boundary, brachiopods with cephalopods (locality F) (Sherwin, 1980a), and brachiopods from locality A (Fig.1 which are Early Devonian in age (Sherwin, 1980b). (See Appendix 2).

##### DATING OF THE WILD WAVE GRANODIORITE

Concentrates of biotite from two samples of drill core from hole G1 were separated and dated using Rb/Sr techniques and precisions (Shaw et al, 1982) at the CSIRO Division of Mineral Physics, North Ryde. Ages were calculated using biotite-bulk rock pairs. An average of four runs on G1 biotite gave an age

TABLE 1

CHEMICAL ANALYSES WILD WAVE GRANODIORITE  
DIAMOND DRILL CORE

SPEC. NO.	G1	G2	G3
SiO <sub>2</sub>	63.99	64.14	64.14
TiO <sub>2</sub>	0.63	0.61	0.59
Al <sub>2</sub> O <sub>3</sub>	15.76	16.06	15.60
Fe <sub>2</sub> O <sub>3</sub>	1.15	1.74	1.41
FeO	3.21	2.94	3.04
MnO	0.06	0.06	0.07
MgO	2.78	3.83	2.35
CaO	3.87	4.26	4.03
Na <sub>2</sub> O	2.79	2.83	2.82
K <sub>2</sub> O	3.73	3.08	3.40
P <sub>2</sub> O <sub>5</sub>	0.31	0.30	0.30
H <sub>2</sub> O <sup>+</sup>	0.99	1.02	1.53
H <sub>2</sub> O <sup>-</sup>	0.11	0.10	0.10
Nb	22	21	27
Zr	150	161	153
Y	19	28	26
Sr	714	768	747
Th	13	19	15
Pb	4	2	5
U	<2	<2	<2
Rb	165	129	144
Zn	38	46	46
Cu	11	14	13
Ni	7	7	6
Cr	31	30	36
V	99	101	103
Ba	811	730	759

## CALCULATED MODE\*

\*BASED ON THE COMPOSITIONS OF HORNBLende AND BIOTITE FROM THE SOUTHERN PART OF THE NEW ENGLAND BATHOLITH (MOONBI NORM OF B.W. CHAPPELL, PERS. COMM.).

SPEC. NO.	G1	G2	G3
QUARTZ	24.1	25.6	25.2
PLAGIOCLASE	37.6	40.8	38.9
K-FELDSPAR	13.9	8.5	12.9
BIOTITE	19.2	20.8	17.4
HORNBLende	4.2	3.3	4.6
APATITE	0.5	0.5	0.5
MAGNETITE	0.5	0.5	0.5

of  $419.0 \pm 1.5$  Ma. Two runs on G2 biotite gave an age of  $416.0 \pm 0.8$  Ma (Table 2). Because of the possibility of radiogenic Sr loss, the estimates are minimum ages only, although the lack of deformation (other than very minor biotite kinking) and regional metamorphic effects suggest the biotite ages represent the time of emplacement and crystallisation. Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios based on biotite bulk rock pairs on samples G1 and G2, average 0.7051 (Table 2).

TABLE 2

## ISOTOPIC DATA, WILD WAVE GRANODIORITE

	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ (p.d.)	Age (Ma)
<u>Biotite Data*</u>					
Spec. No.					
G1	585.77	23.64	74.8817	1.15205	418.93
Dupl 1.G1	593.13	23.62	75.9309	1.15670	417.43
Dupl 2.G1	589.90	23.18	76.9921	1.16446	418.76
Dupl 3.G1	589.86	26.43	67.1590	1.10789	420.95
				Av	$419.0 \pm 1.5$
G2	393.96	36.41	31.8199	0.89329	415.44
Dupl 1.G2	392.49	30.15	38.5390	0.93363	416.51
				Av	$416.0 \pm 0.8$
<u>Rock Data</u>					
Spec. No.					
G1	165	714	0.66934	0.70926	-
G2	129	768	0.48644	0.70790	-

\*Age calculated from biotite-bulk rock pair. Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios - G1 = 0.70527, G2 = 0.70501.

The average age of G1 and G2 combined is  $418 \pm 2$  Ma

Biotite separates were prepared by rolling and sieving. Coarse-grain size (+80 mesh) and apatite inclusions probably account for variations in the values of Sr.

Errors in biotite Rb and Sr determinations based on replicate analyses of NBS 607 K feldspar are estimated to be less than 0.2% (standard error of the mean %). Unspiked  $^{87}\text{Sr}/^{86}\text{Sr}$  of SRM 987 gave  $0.71036 \pm 0.00011$  (standard error of the mean).

$\lambda^{87}\text{Rb} = 1.42 \times 10^{-11} \text{ yr}^{-1}$ . Normalised to  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ .

## CONCLUSIONS

As outlined above, nonconformable relations in the Cobar Lucknow area occur between sediments of the Early Devonian Meryula Formation and the underlying Silurian I-type, Wild Wave Granodiorite which is intrusive into the Ballast beds of the Girilambone Group. Sample G2 ( $416.0 \pm 0.8$  Ma) is slightly younger than sample G1 ( $419.0 \pm 1.5$  Ma). If real, this difference may reflect the greater alteration of biotite to chlorite in sample G2. The average biotite Rb/Sr age of the Wild Wave Granodiorite of  $418 \pm 2$  Ma (combining G1 and G2) is interpreted to be a minimum age representing the time of cooling after high level emplacement. Taking the base of the Silurian as 436 Ma (Lanphere et al, 1977), and the base of the Devonian as 410 Ma (Armstrong & McDowall 1975, Owen & Wyborn 1979, Richards et al, 1977), this date falls around the boundary between the Middle and Late Silurian.

The age data on the Wild Wave Granodiorite can be compared with data from other Silurian granitoids in the Girilambone-Wagga Anticlinorial Zone. North of the Lachlan River, the oldest minimum age for the Thule Granite (K/Ar on biotite) is  $422 \pm 6$  Ma. Pogson & Hilyard (1981) estimated a maximum age of 440 Ma for the foliated phase of the Nymagee Igneous Complex. South of the Lachlan River, the Kikora Granite gives a corrected\* K/Ar age of  $417 \pm 3$  Ma (Richards et al, 1982). These latter authors also report ages of  $417 \pm 2.5$  Ma (Rb/Sr mica concentrate) on the Mine Granite at Ardlethan and  $410 \pm 2.5$  Ma (Rb/Sr and K/Ar) on the Ardlethan Granite.

Geochemical identification of the Wild Wave Granodiorite as an I-type intrusive is supported by the identification of hornblende and magnetite, the latter also reflected in the geophysics. With the exception of the I-type Tibooburra Granite with a K/Ar biotite age around 403 Ma (Evernden & Richards 1962, corrected to new constants) and a Rb/Sr biotite age around 410 Ma (Shaw & Flood, 1982), the Wild Wave Granodiorite lies further west than most of the I-type granitoids recorded from N.S.W. To date this body is the only Silurian I-type body identified in that part of the Girilambone-Wagga Anticlinorial Zone lying north of the Lachlan River: the Nymagee Igneous Complex, Thule Granite and Erimeran Granites are all S-types (Pogson, 1982), as may be the Tinderra Granite. Based on the models of Chappell & White (1974), this difference in granite types reflects differences in melt source material; the I-type being generated by melting of an igneous source, the S-type from melting of a sedimentary source. Pogson (1982) noted that the Thule and Erimeran Granites and the Nymagee Igneous Complex are low Ca granites in the sense of Fagan (1979), and suggested that they formed by partial melting of the quartz-rich, Ca-poor rocks of the Girilambone Group.

The age of the Wild Wave Granodiorite source rock material can be calculated, providing

assumptions of Rb/Sr and initial  $^{87}\text{Sr}/^{86}\text{Sr}$  are made. Compston & Chappell (1979), in a study of granitoids of the southern part of the Lachlan Fold Belt, calculated source rock Rb/Sr compositions varying from 0.066 to 0.22, and initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios varied from 0.7031 to 0.7042. Alternatively, source compositions can be estimated from the extrapolation of modern day island arc volcanics. Typical Rb/Sr ratios vary from 0.02 to 0.08, and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios average 0.7037. On a mantle growth curve, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio would extrapolate to approximately .7031, at between 1000 Ma and 1200 Ma.

Thus assuming a source Rb/Sr ratio of 0.066, and an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.7031, equivalent to the lowermost values of Compston & Chappell (1979), the age of the Wild Wave Granodiorite source would be 1100 Ma, similar to that calculated by Compston & Chappell for source material of their "non-minimum-melt" granitoids. This calculated source age is considered to be a maximum only, and on this basis would correspond to a Proterozoic rather than a Lower Palaeozoic source.

From the granitoid data just discussed, we summarise our conclusions as follows:

- 1) The period around 420 Ma was marked in the Girilambone-Wagga Anticlinorial Zone by emplacement of large volumes of granitoids. This implies a high heat flow under a large part of this area at this time, or just earlier.
- 2) Generation of the S-type granitoids at mid crustal levels (Pogson, 1982) implies a high heat source.
- 3) The I-type Wild Wave Granodiorite probably formed at a deeper level than the S-type granitoids, from a more mafic lower crust. Rise of this melt to its present position was probably accomplished up a major crustal fracture during a period of crustal extension. This would account for the location of the Wild Wave Granodiorite lying within the Cobar-Inglewood Lineament.
- 4) The low initial ratio of the I-type Wild Wave Granodiorite would suggest that its source material is Upper Proterozoic or younger, similar to that proposed by Compston & Chappell (1979) for the southern part of the Lachlan Fold Belt.

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APPENDIX 1. Petrography of the Wild Wave  
Granodiorite (based on observation and part from  
Barron, 1960).

- G1. quartz-feldspar-hornblende-biotite granodiorite  
Quartz (24%, 0.6-0.8mm) slightly stained with  
undulose extinction and minor bulging along  
quartz/quartz and quartz/feldspar boundaries.  
Plagioclase (40%, 0.3-1.7mm) subhedral, well  
twinned and concentrically zoned. Minor  
replacement by "sericite". K feldspar  
(14%, to 3mm). Some micropertthite. Hornblende  
(4%, 0.8-1.4mm) pale green-yellow subhedral-  
anhedral grains up to 1mm. Minor alteration  
to carbonate, ?sphene and chlorite. Poikilitic  
with inclusions of quartz and feldspar. Good  
equilibrium texture. Also occurring as inter-  
growths with biotite, with biotite probably  
replacing some hornblende. Biotite as above  
and also (15%, 0.4-2mm) discrete subhedral to  
anhedral grains. Inclusions of quartz and  
needles of ? rutile. Random preferred  
orientation. Some bending of (001) traces  
and some alteration and opening along (001).  
Alteration to chlorite in places. Minor  
sphene, epidote, zircon, apatite and  
magnetite.
- G2. as above. Biotites more altered to chlorite,  
and more magnetite. Good evidence for some  
biotite replacing hornblende. Rock frag-  
ments of microdiorite.
- G3. as G1. Biotites less altered than those in  
G2; more like G1. Magnetite like G2. Good  
equilibrium textures between hornblende (to  
4mm), quartz and feldspar. Magnetite  
associated with hornblende and biotite.

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APPENDIX 2. Palaeontology

- Locality A Brachiopods ?Atrypa sp.  
(poorly preserved)  
Early Devonian  
Sherwin (1980a).
- Locality B Brachiopods. ?Plectatrypa sp.  
?Centronella sp.  
?Schizotreta sp.  
  
Indet. dalmanellids,  
rhynchonellids, strophomenids  
  
Corals ? Alveolites sp.  
Early Devonian (?)  
Sherwin (1974a), Baker (1978 App.1)
- Locality C Crinoid stems (large)  
Sherwin (1980b)
- Locality D Trilobites Encrinurus sp.  
?Gravicalymene sp.  
  
Brachiopods indet. stropheodontids  
  
Early Devonian  
(Sherwin (1980b))
- Locality E Echinoderm debris  
(Sherwin (1980b))
- Locality F Brachiopods indet. ?strophomenids  
Cephalopods orthoconic, nautiloids  
  
Early Devonian  
Sherwin (1980b)
- Locality G Trilobites Gravicalymene  
  
Brachiopods ?Protochonetes sp.  
  
?Howellella sp.  
  
Cephalopods Michelinoceras sp.  
  
Tentaculitids Nowakia cf acuaria  
(Richter)  
  
?Tentaculites sp.  
  
Early Devonian  
Sherwin (1974), Baker  
(1978 App.1).

## Astrometric Determination of Mass Segregation and Membership Probabilities in Galactic Clusters

DAVID S. KING

**ABSTRACT.** Using positional as well as proper motion information allows a more reliable determination of the membership probabilities in the region of galactic clusters. Applying a positional fit to cluster members indicates that the more massive stars congregate towards the cluster centre in NGC 6087 and NGC 3532.

### INTRODUCTION

In a previous paper (King 1979), a method was described whereby a probability of membership could be assigned to stars in the region of a galactic cluster. This probability was calculated on the basis of proper motion only. The inclusion of positional information gives a more reliable membership probability and allows a test to be made to ascertain if the more massive cluster stars congregate towards the cluster centre.

### THE PROBABILITIES

The method described in the previous paper (King 1979) was devised by Sanders (1971) and involved representing the observed proper motions as two overlapping bivariate gaussian frequency functions. Using the maximum likelihood method enabled the seven parameters in the distribution equation to be estimated. The drawback with this method was that it gave high probabilities of membership to stars with similar proper motion to the cluster no matter how far they were from the cluster centre.

Incorporating positional as well as velocity information into the distribution equation offers twice the information at the expense of five extra parameters. It is assumed that the field stars are uniformly distributed over the area studied and the cluster stars are distributed in three dimensions like a polytrope of index five. A polytrope of index five (Plummer's model) consists of a finite distribution of mass which is infinite in extent. Seen in projection, Plummer's model obeys the following density equation with  $r$  being the distance from the centre and  $R$  the radius containing half the mass in projection.

$$\rho(r) = \frac{1}{\pi R^2} \left[ 1 + \frac{r^2}{R^2} \right]^{-2}$$

Plummer (1911) was the first to suggest that globular star clusters obeyed this distribution law. More recently, it has been used as the starting model for computer simulation of star clusters. Combining Plummer's model with the proper motion distribution model gives the following distribution equation:-

$$\phi(\mu_i, v_i, \xi_i, \eta_i) = \phi^f + \phi^c$$

$$\begin{aligned} &= \frac{N_f}{2\pi \Sigma_x \Sigma_y A} \exp \left[ -\frac{1}{2} \left[ \frac{(\mu_i - X_f)^2}{\Sigma_x^2} + \frac{(v_i - Y_f)^2}{\Sigma_y^2} \right] \right] \\ &+ \frac{N_c}{2\pi \sigma_c^2 R_{\xi} R_{\eta}} \left[ 1 + \frac{(\xi_i - \xi_c)^2}{R_{\xi}^2} + \frac{(\eta_i - \eta_c)^2}{R_{\eta}^2} \right]^{-2} \exp \left[ -\frac{1}{2} \left[ \frac{(\mu_i - X_c)^2}{\sigma_c^2} + \frac{(v_i - Y_c)^2}{\sigma_c^2} \right] \right] \\ &= \frac{N_f}{2\pi \Sigma_x \Sigma_y A} \alpha + \frac{N_c}{2\pi \sigma_c^2 R_{\xi} R_{\eta}} \gamma \beta \end{aligned}$$

The unknowns in the distribution equation are  $\sigma_c$ , the dispersion of the cluster star motions;  $N_f$ ,  $N_c$  the number of field and cluster stars;  $X_f$ ,  $Y_f$  the centre of the field star proper motion distribution;  $X_c$ ,  $Y_c$  the centre of the cluster star proper motions, previously assumed to be zero;  $\Sigma_x$ ,  $\Sigma_y$  the field star proper motion dispersions;  $\xi_c$ ,  $\eta_c$  the cluster centre and  $R_x$ ,  $R_y$  the cluster radii containing half the mass in projection. There are an additional two unknowns;  $\theta$  the rotation angle of the observed proper motions ( $+\mu$  to  $+\nu$ ) into a new coordinate system defined by the principal axes of the apparent ellipsoidal distribution of field star motions; and  $\psi$  the rotation angle of the positions ( $+\xi$  to  $+\eta$ ) into new positional coordinates defined by the principal axes of the cluster. The positions  $\xi_i$ ,  $\eta_i$  and the velocities  $\mu_i$ ,  $\nu_i$  are then obtained in their new coordinate systems.  $A$  is the area for which positions and velocities are known.

The method of maximum likelihood then gives the following non-linear equations of condition:-

$$N_f : \sum_{\phi} \frac{1}{\left[ \frac{\alpha}{\Sigma_x \Sigma_y A} - \frac{\gamma \beta}{\pi \sigma_c^2 R_{\xi} R_{\eta}} \right]} = 0$$

$$X_f : \sum_{\phi} \frac{\alpha}{\left[ \mu_i - X_f \right]} = 0$$

$$Y_f : \sum_{\phi} \frac{\alpha}{\left[ \nu_i - Y_f \right]} = 0$$

$$\Sigma_x : \sum_{\phi} \frac{\alpha}{\left[ \frac{(\mu_i - X_f)^2}{\Sigma_x^2} - 1 \right]} = 0$$

$$\Sigma_y : \sum_{\phi} \frac{\alpha}{\left[ \frac{(\nu_i - Y_f)^2}{\Sigma_y^2} - 1 \right]} = 0$$

$$\sigma_c : \sum_{\phi} \frac{\gamma \beta}{\left[ \frac{(\mu_i - X_c)^2 + (\nu_i - Y_c)^2}{\sigma_c^2} - 2 \right]} = 0$$

$$\theta : \sum_{\phi} \frac{1}{\left[ \frac{N_f \alpha}{\Sigma_x \Sigma_y A} \left[ \frac{\nu_i (\mu_i - X_f)}{\Sigma_x^2} - \frac{\mu_i (\nu_i - Y_f)}{\Sigma_y^2} \right] + \frac{N_c \gamma \beta}{\pi \sigma_c^2 R_{\xi} R_{\eta}} \left[ \frac{\mu_i Y_c - \nu_i X_c}{\sigma_c^2} \right] \right]} = 0$$

$$X_c : \sum_{\phi} \frac{\gamma \beta}{\left[ \mu_i - X_c \right]} = 0$$

$$Y_c : \sum_{\phi} \frac{\gamma \beta}{\left[ \nu_i - Y_c \right]} = 0$$

$$\xi_c : \sum_{\phi} \frac{\beta \gamma^{1.5}}{\left[ \xi_i - \xi_c \right]} = 0$$

$$n_c : \sum \frac{\beta \gamma^{1.5}}{\phi} \left[ \eta_i - \eta_c \right] = 0$$

$$R_\xi : \sum \frac{\gamma \beta}{\phi} \left[ \frac{4 \gamma^{0.5} (\xi_i - \xi_c)^2}{R_\xi^2} - 1 \right] = 0$$

$$R_\eta : \sum \frac{\gamma \beta}{\phi} \left[ \frac{4 \gamma^{0.5} (\eta_i - \eta_c)^2}{R_\eta^2} - 1 \right] = 0$$

$$\psi : \sum \frac{\beta \gamma^{1.5}}{\phi} \left[ \frac{\eta (\xi_i - \xi_c)}{R_\xi^2} - \frac{\xi (\eta_i - \eta_c)}{R_\eta^2} \right] = 0$$

The summations being over the known total population ( $N_c + N_f$ ).

The previous 14 equations are solved by assuming initial values then calculating the value of each parameter in turn. After several iterations the parameters converge in most cases. Thus, the probability of membership is determined for star  $i$  as:-

$$P_i = \frac{\phi_i^c}{\phi_i^c + \phi_i^f}$$

Field stars which fail to fit the gaussian field star distribution due to local motion and differential galactic rotation are pruned one at a time until the distributions, given by proper motion only, reach their best fit. This method gives two probabilities of membership, the first using only the proper motions and the second using proper motion and positional information.

#### CASE STUDY OF NGC 6087

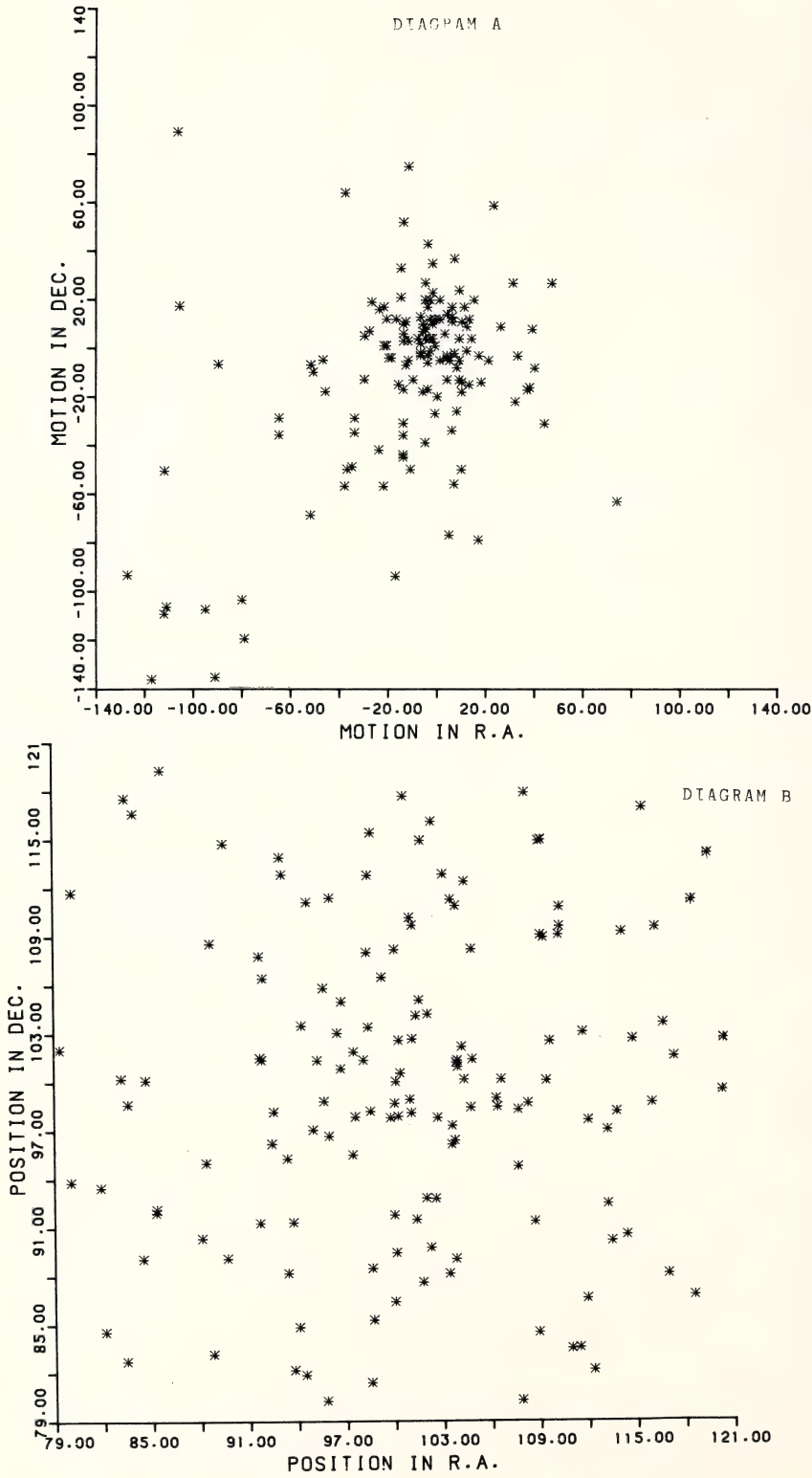
The above procedure for obtaining two membership probabilities was applied to the galactic cluster NGC 6087 (King 1982). It was found that the nine parameters in common to both types of distribution function were in reasonable agreement, although the number of field stars increased with the inclusion of positional information. This was to be expected for the reason given earlier, that field stars with cluster type motion were previously given cluster status no matter how far they were from the cluster centre.

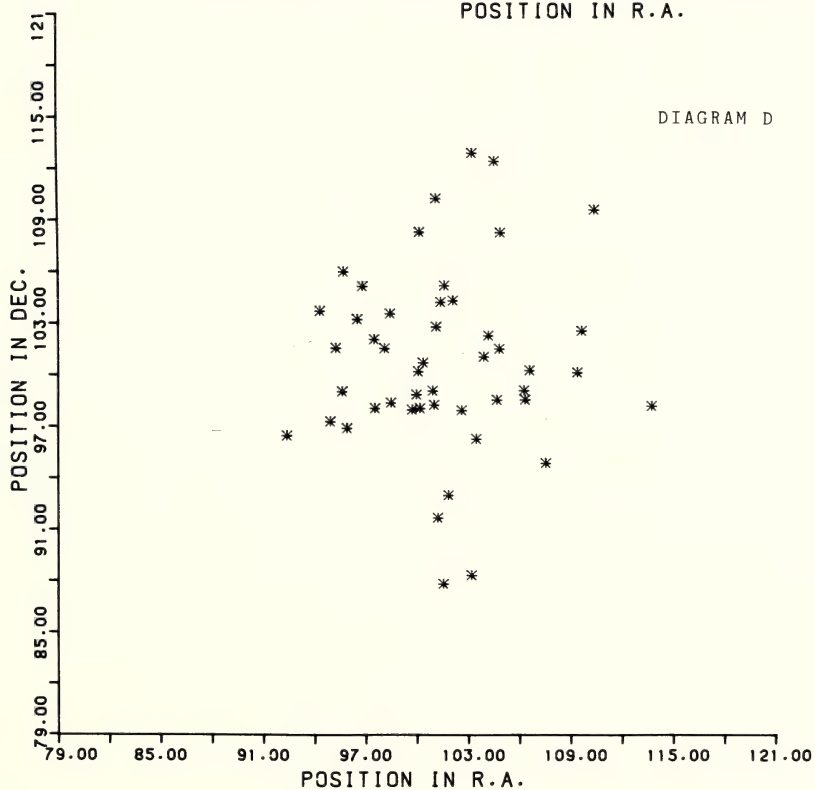
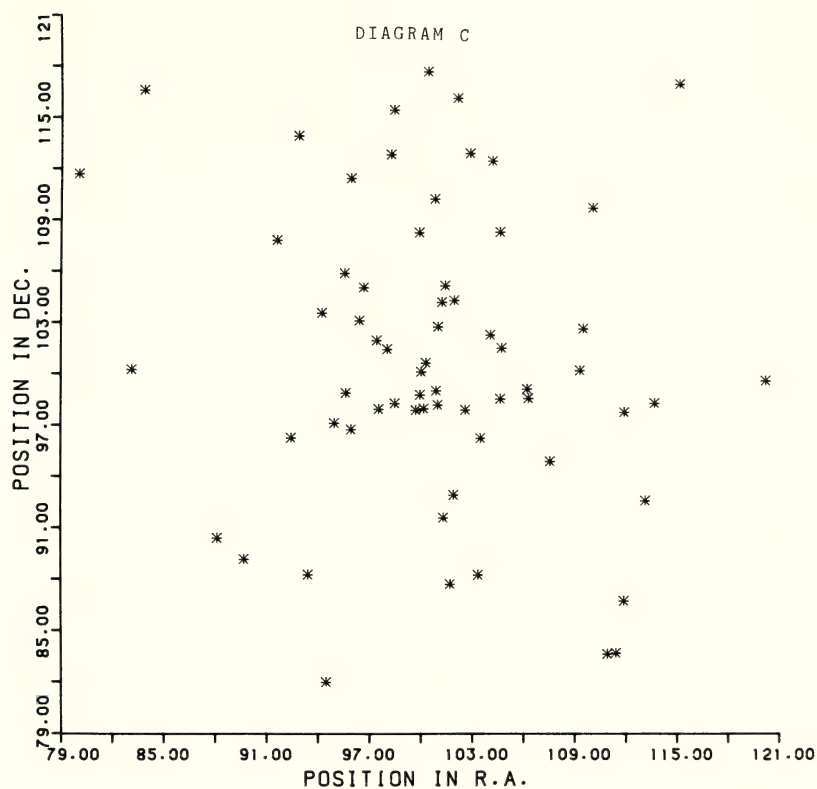
To illustrate the effect that positional parameters have on the membership probabilities, the following diagrams were produced. Diagram A is the proper motion plot for stars with motions less than 1.4 seconds of arc per century. It can be easily seen that it is composed of two binormal distributions. One distribution is circular centred on zero which represents the cluster stars all moving together. The other distribution represents the field stars and is elliptical, more extensive and has its major axis at 36 degrees to the right ascension axis. It is by resolving stars into these two components that the probabilities based on proper motion are derived.

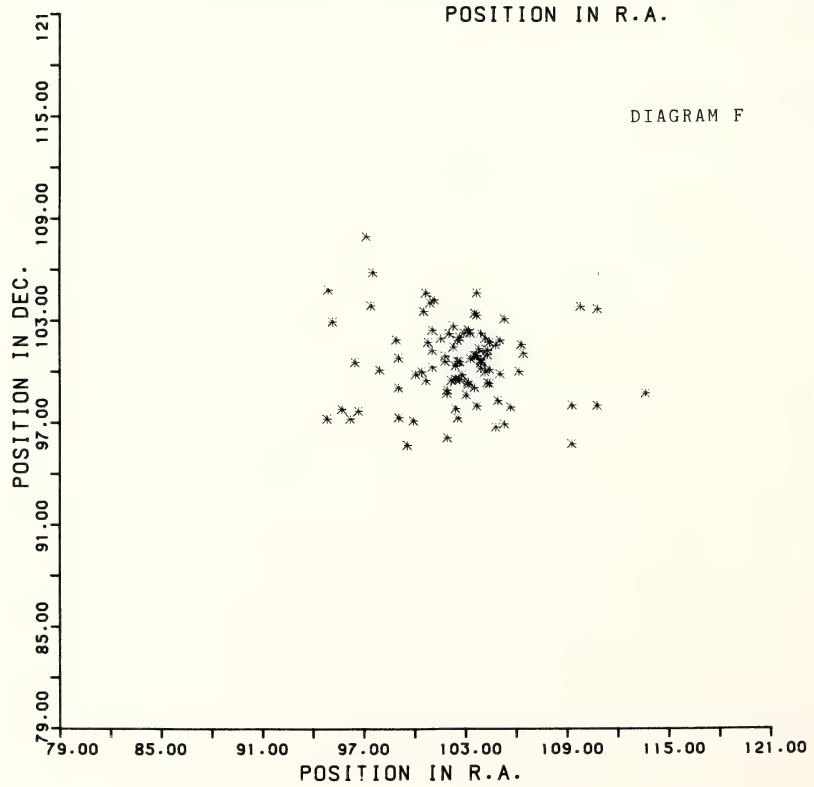
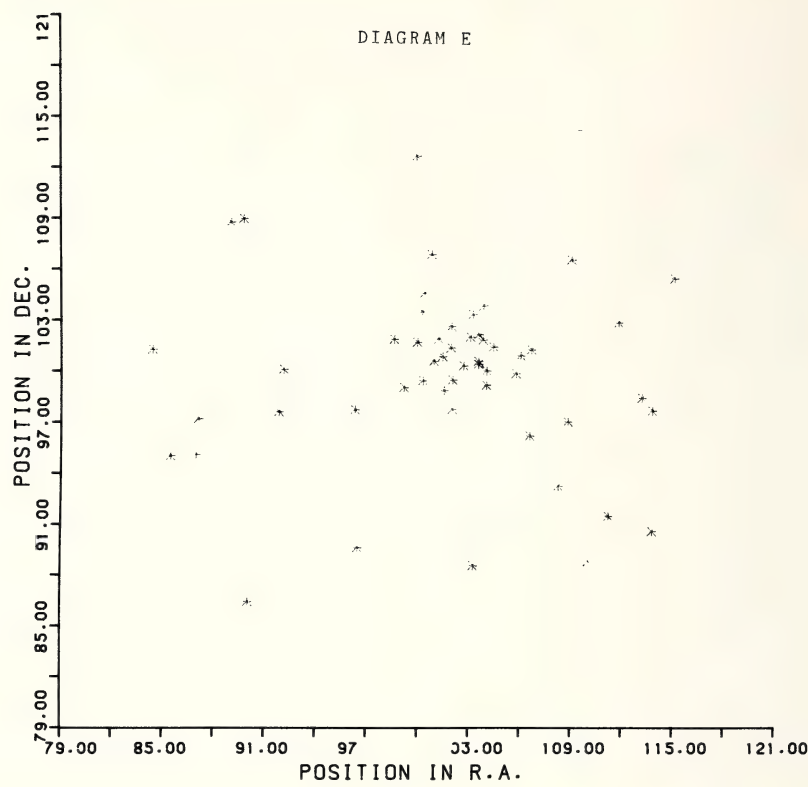
Diagram B shows us the positional information we have available for stars in the region of NGC 6087. The star at position (100.0, 100.0) is at right ascension  $16^h 14^m 40.2^s$  and declination  $-57^\circ 47' 13.8''$ . The axes are in millimetres and one millimetre represents one second of arc. When only the stars with probabilities of membership greater than 90% are plotted, diagrams C and D are produced. Diagram C gives the positions of 65 stars with membership probabilities greater than 90% based on proper motion only. Diagram D gives the positions of 47 stars with membership probabilities greater than 90% based on position as well as proper motion. Diagram D has excluded stars from membership that lie a long way from the cluster centre as well as included some extra stars close to the cluster centre.

#### CASE STUDY OF NGC 4755

Membership probabilities were also determined for the galactic cluster NGC 4755 using both methods. Previously only probabilities using proper motions were published (King 1980). Diagram E shows the field stars in the region of the cluster on the basis of proper motion. Diagram F was obtained by using proper motion as well as position to find the non-members. The difference between the two diagrams is a striking







example of the discrimination of the new method. Diagram E obviously has some stars left in it which are members, whereas diagram F appears to be a random distribution of field stars. This difference in the appearance of field stars was also present in NGC 6087, but did not appear so clearly.

#### MASS SEGREGATION

Because of the positional information given by the additional parameters in determining the new probabilities, it becomes possible to make a quantitative estimate of the diameter of the cluster. For NGC 6087, 78 members on the basis of position and velocity were selected. Using the method of maximum likelihood, the five parameters relating to positional information were obtained. The value of  $R_\xi$  is 6.18 and  $R_\eta$  is 8.14. The 78 members were divided into two different magnitude ranges, one between magnitudes 7.5 and 10.6 and the other between 10.6 and 11.1. The average magnitude in the first group is 9.95 and in the second group is 10.9.

Assuming the distance to NGC 6087 is 910 pc (Landolt 1963), then these magnitudes correspond to solar masses of 3.6 and 2.5 respectively. The 39 bright members gave the value of  $R_\xi$  as 6.13 and  $R_\eta$  as 7.12. The 39 faint members gave the value of  $R_\xi$  as 7.12 and  $R_\eta$  as 9.16.

This provided some evidence of mass segregation of the heavier stars towards the cluster centre as predicted by the computer simulation of clusters. However, the number of stars is insufficient to draw any firm conclusion, so a previously studied cluster NGC 3532 (King 1978) was examined. Using the method already described, 237 members were selected. The results are in Table 1.

Table 1 - Radius of NGC 3532

	237 members	118 bright members	119 faint members
$R_\xi$	10.4	9.9	10.6
$R_\eta$	8.2	6.9	9.5

The 118 bright members have an average magnitude of 9.12 which at 430pc (Schmidt 1963) corresponds to 2.7 solar masses. The 119 faint members have an average magnitude of 10.52 corresponding to 1.9 solar masses. This provides a strong indication of mass segregation in galactic clusters.

#### LIST OF DIAGRAMS

- DIAGRAM A - Proper motions in the region of NGC 6087. Motions of stars in right ascension (R.A.) and declination (DEC.) are in units of 0.01 per century.
- DIAGRAM B - Stars in the region of NGC 6087. Positions of stars are shown with (100.0, 100.0) corresponding to R.A.  $16^h 14^m 40^s.2$ , Dec.  $-57^\circ 47' 13''.8$ . The axes are in millimetres and one millimetre represents one second of arc.
- DIAGRAM C - Members of the cluster NGC 6087 using proper motion. Positions of cluster members with probabilities of membership greater than 90% based on proper motion only are shown.
- DIAGRAM D - Members of the cluster NGC 6087 using positional and velocity information. Positions of cluster members with probabilities of membership greater than 90% based on proper motion and position are shown.
- DIAGRAM E - Field stars in the region of NGC 4755 on the basis of proper motion. Positions of non-members with probabilities of membership less than 50% based on proper motion only are shown.
- DIAGRAM F - Field stars in the region of NGC 4755 on the basis of positions and velocities. Positions of non-members with probabilities of membership less than 50% based on proper motion and position are shown.

#### CONCLUSION

Provided a large area is examined surrounding a galactic cluster, and all stars are examined down to a fixed magnitude limit, it is possible to obtain a clear distinction between cluster and field stars by taking into account both proper motion and positional data. Cluster members determined in this manner may exhibit mass segregation of the heavier stars toward the cluster centre. Further examination of the mass segregation may be used to compare models of cluster evolution.

#### ACKNOWLEDGMENTS

The author wishes to acknowledge the support of the University of Sydney on whose computer the membership models were calculated as contribution toward a Ph.D. thesis entitled "Open Cluster Dynamics; a Comparison of Theory, Simulation and Observation".

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Sydney Observatory,  
Observatory Park,  
SYDNEY. N.S.W. 2000

(Manuscript received 10.6.1983)

## MEETINGS

Council held 11 meetings during the past year. Attendance of members of Council ranged from 10 to 14.

Nine general monthly meetings were held during the year together with the Liversidge Lecture delivered by Professor D.P. Craig on "Molecular Crystals and Light: Chemical Reactions in Cages" on 20th May, 1982 at Macquarie University. Abstracts of the lectures at the monthly meetings have been published in the Society's Newsletter. The average attendance at the general monthly meetings was 24. (range 17 to 35).

## ANNUAL DINNER

The Annual Dinner was held at the Great Hall of the University of Sydney on Wednesday, 2nd March, 1983, and 91 members and guests were present. We commemorated the centenary of the Faculties of Medicine and Engineering of the University of Sydney, and Professor J.M. War, the Vice-Chancellor and Principal gave the address.

## PUBLICATIONS

Volume 115, Parts 1 to 4, of the Journal and Proceedings were published during the year.

There were 10 issues of the Society's Newsletter. Council is most grateful to the authors of short articles which are much appreciated by members.

## MEMBERSHIP

The membership of the Society at 31st March, 1983 was:

Honorary Members	12
Life Members	35
Company Member	1
Ordinary Members	327
Associate Members	40

## LIBRARY

There were a total of 98 requests for photocopying from the library during the year. Of these 9 requests were from members, and the remaining 89 from institutions, mainly Universities and Colleges (40), Commonwealth and State Government Departments (30), private firms (9), museums (5), and sundry research institutions (5).

A total of 2211 items were received and processed from 375 institutions, mainly through exchange of the Journal and Proceedings.

Council expresses great gratitude to Mr. J.L. Griffith, the Honorary Librarian, and to Mrs. Grace Proctor, the Honorary Assistant Librarian, for all of their work during the year.

Because of the imminent sale of the Science Centre building, Council resolved, at its meeting on 30th March, 1983, that the library books and shelving be moved from the space presently occupied by 31st May, 1983 or as soon thereafter as possible, and that accessioning of serials and

provision of service in photocopying and facilities for readers cease on Thursday 28th April, 1983.

## AWARDS

The following awards for 1982 were made:

Clarke Medal:	Emeritus Professor Noel Charles William Beadle
Edgeworth David Medal:	Nhan Phan-Thien
The Society Medal:	William Broderick Smith-White
Liversidge Research Lectureship:	Professor D.P. Craig.

## SUMMER SCHOOL

A most successful Summer School in Engineering was held at the University of Sydney from 24th to 28th January, 1983. 80 students, who had completed Year 11, attended the School. The School covered a wide range of engineering topics, and included visits to I.C.I., Qantas, Pyromont Power Station, Railways Signalling and Control, Telecom Exchange, and MWS and DB Treatment Works, North Head.

## FINANCE

The audited Annual Accounts accompanying this report show that the Society's *normal* funds are in as good a state as can be expected in these difficult times and that the operations in 1982 resulted in a deficit of \$614. The deficit resulted almost entirely from the reduction in the N.S.W. Government grant from \$1600 in 1981 to \$1000 in the year of the account. Fortunately it was possible to balance unavoidable rises in the cost of some items by increased revenue from investments.

Unfortunately the overall outlook for the *bulk* of the Society's total assets of about \$520,000 is not bright. You will note that the Auditor has qualified the Accounts, pointing out that there is a very substantial deficiency of shareholders' funds in the Society's joint venture with the Linnean Society of N.S.W. - "Science House Pty. Ltd." In the light of the Auditor's report we must very regretfully prepare ourselves for the possibility that over \$400,000 of the Society's assets, lent as an unsecured loan to Science House Pty. Ltd., may not be recoverable in part or whole. The year 1983 should see a resolution of the uncertainties over this matter. Some members of your Council, including the Honorary Treasurer, have not regarded as realistic the continuing optimism amongst the supporters of Science House Pty. Ltd. that it will be able to resolve its difficulties and survive; the interst burden (\$2M) on the original mortgage loan (\$1.5M) has become too large ever to reduce by trading alone, and a sale of the Science Centre building appears inevitable. Financial planning for the Society in 1983 has thus to allow for the contingency that substantial relocation expenses may be incurred if the Society is forced to move its office and possessions.

Council is grateful to the New South Wales Government for its grant through the Division of Cultural Activities in the Premier's Department.

## SCIENCE CENTRE

Council's representatives on the Board of Science House Pty. Ltd. continued to be Mr. M.J. Puttock (Chairman), Mr. E.K. Chaffer, Mr. J. W. Humphries and Associate Professor W.E. Smith. They gave considerable attention to the financial difficulties of the Company and warned Council that in 1983 substantial changes in arrangements would probably be necessary.

The Science House Pty. Ltd. Secretariat serviced 21 scientific societies during the year - a benefit which they greatly appreciated.

## ACKNOWLEDGEMENTS

Mrs. Judith Day and Mrs. Grace Proctor in the past year have continued to give great assistance and service to the Society and its members.

Council would also like to record its thanks to all those who contributed to the success of the Summer School in Engineering, especially to Professor T.W. Cole, of the School of Electrical Engineering who organized the Summer School.

## FINANCIAL STATEMENTS

**For the year ended 31st December, 1982**

## AUDITORS REPORT

The Society advanced an amount of \$416995 to Science House Pty Limited in 1974 (refer note 3) which amount appears in the Balance Sheet as an "Unsecured Loan to an Associated Corporation". The accounts of Science House Pty Limited, as at 30th June 1982, show a deficiency in shareholders funds of \$708170. We have been unable to confirm that a material improvement in this situation has emerged prior to the date of this report and accordingly we are of the opinion that some or all of the loan money may not be recoverable.

No provision for the non-recoverability of this loan has been made in the accounts of the Society.

Subject to the above, in our opinion:

- (a) the attached Balance Sheet and Income and Expenditure Account, which have been prepared under the historical costs convention, are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society at 31st December 1982 and of the results of the Society for the year ended on that date; and
- (b) the accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules.

WYLIE & PUTTOCK  
Chartered Accountants.

By ALAN M. PUTTOCK  
Registered under the Public Accountants  
Registration Act, 1945 as amended.

## BALANCE SHEET as at 31/12/82

[illegible]

FINANCIAL STATEMENTS

NOTES TO AND FORMING PART OF THE ACCOUNTS  
For the Year Ended 31st December 1982

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December 1982. Unless otherwise stated, such accounting policies were also adopted in the preceding year.

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs.

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

- Furniture 7.50%
- Office Equipment 15.00%

(c) Library Fund

During the 1980 year an amount was transferred from the Library Fund to Accumulated Funds as a contribution to the cost of providing the library with a programme of book purchases. The programme is the subject of a Memorandum of Understanding with the other Societies are acquired for the Library. This procedure was not adopted in the current year.

(d) Library Facilities

Certain donations to the Society's Library Fund have been paid to Science House Pty Limited (see also note 3) towards the cost of providing library facilities for the Society. Such payments represent donations specifically designated by the donor as being for that purpose.

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

7310.57	Balance at 1st January	7310.57
-----		-----
7310.57	Balance at 31st December	7310.57
=====		=====

(b) Resumption Reserve

416991.00	Balance at 1st January	416991.00
-----		-----
416991.00	Balance at 31st December	416991.00
=====		=====

Represented by:

1.00	Shares in Associated Corporation	1.00
-----		-----
416990.00	Loan to Associated Corporation	416990.00
-----		-----
416991.00		416991.00
=====		=====

MOVEMENTS IN PROVISIONS AND RESERVES (cont.)

(c) Library Fund

2305.57	Balance at 1st January	2708.13
5452.36	Add Donations and bank interest	381.65
-----		-----
7757.93		3089.78
49.80	Less Library purchases	
	Paid re library facilities	50.00
5000.00		-----
-----		-----
5049.80		50.00
2708.13	Balance at 31st December	3039.78
=====		=====
462.48	Represented by:	244.13
2300.00	Cash at Bank	2900.00
54.35	Commonwealth bonds and inscribed stock	104.35
-----		-----
2708.13	Owing to general funds	3039.78
=====		=====

3. LOAN TO ASSOCIATED CORPORATION

The Society has entered into a joint venture with the Linnean Society for the establishment and operation of a Science Centre for New South Wales to provide facilities for professional, scientific and academic institutions. To facilitate this, a company, Science House Pty Limited, has been formed in which each Society has a 50% interest. Advances and loans to the company have been on an interest free basis repayable at call. No material repayments are anticipated prior to 31st December, 1983.

419994.61	Balance at 1st January	419994.61
-----		-----
419994.61	Balance at 31st December	419994.61
=====		=====
416990.00	Representing Resumption Reserve	416990.00
3004.61	Accumulated funds	3004.61
-----		-----
419994.61		419994.61
=====		=====

# FINANCIAL STATEMENTS

45

## 4. TRUST FUNDS

### Clarke Memorial Fund - Capital

4800.00	Balance at 1st January	4800.00
0.00	Capitalisation of	200.00
-----	Accumulated Revenue	-----
4800.00	Balance at 31st December	5000.00
-----		-----
545.00	Revenue Income for Period	651.00
474.74	Less Expenditure for	1344.42
-----	Period	-----
70.26		(693.42)
1172.75	Balance at 1st January	1243.01
-----		-----
1243.01	Less Capitalisation	549.59
0.00		200.00
-----		-----
1243.01	Balance at 31st December	349.59
-----		-----
6043.01		5349.59

### Walter Burfitt Prize Fund - Capital

3000.00	Balance at 1st January	3000.00
-----		-----
3000.00	Balance at 31st December	3000.00

### Walter Burfitt Prize Fund - Revenue

341.00	Revenue Income for Period	391.00
186.23	Less Expenditure for	0.00
-----	Period	-----
154.77	Balance at 1st January	391.00
1078.50		1233.27
-----		-----
1233.27	Balance at 31st December	1624.27
-----		-----
4233.27		4624.27

### Liversidge Bequest Fund - Capital

2000.00	Balance at 1st January	2000.00
0.00	Transfer from	1000.00
-----	Accumulated Funds	-----
2000.00	Balance at 31st December	3000.00

### Liversidge Bequest Fund - Revenue

227.00	Revenue Income for Period	391.00
30.20	Less Expenditure for	474.10
-----	Period	-----
196.80		(83.10)
(13.16)	Balance at 1st January	183.64
-----		-----
183.64	Balance at 31st December	100.54
-----		-----
2183.64		3100.54

### Olle Bequest Fund - Capital

1300.00	Balance at 1st January	4000.00
2461.00	Bequest Capital Received	0.00
-----	Capitalisation of	-----
239.00	Accumulated Revenue	0.00
-----		-----
4000.00	Balance at 31st December	4000.00

### Olle Bequest Fund - Revenue

366.12	Revenue Income for Period	521.00
0.00	Less Expenditure for	224.25
-----	Period	-----
366.12		296.75
868.27	Balance at 1st January	995.44
-----		-----
1234.39	Less Capitalisation	1292.19
238.95		0.00
-----		-----
995.44	Balance at 31st December	1292.19
-----		-----
4995.44		5292.19
-----		-----
17455.36	Total Trust Funds	18366.59
=====		=====

## STATEMENT OF SOURCE AND APPLICATION OF FUNDS For the Year Ended 31st December 1982

### SOURCE OF FUNDS

Operating surplus for the year	776.00	0.00
Add:		
Items not involving the outlay of funds in the current period:		
Depreciation of fixed assets	579.00	0.00
Provision for doubtful debts	921.00	0.00
-----	-----	-----

Funds derived from		
Operations	2276.00	0.00
Donations and interest		
To Liversidge Fund	5452.00	381.65
Trust fund income	1479.00	1954.00
Trust fund bequests -		
Olle Estate	2461.00	0.00
Proceeds Estate Late		
W.F. Poggenдорff	0.00	5000.00
-----	-----	-----
11668.00		7335.65
=====		=====

### APPLICATION OF FUNDS

Operating deficit for the year	0.00	614.02
Less:		
Items not involving the outlay of funds in the current period:		
Depreciation of fixed assets	0.00	523.00
Provision for doubtful debts	0.00	1348.12
-----	-----	-----

Funds applied to		
Operations	0.00	(1257.10)
Reclassification of life members subscriptions		
Increase in investments	19.00	19.37
Trust fund expenses	2520.00	5600.00
Library facilities	692.00	2042.77
Increase in working funds	5000.00	930.61
-----	-----	-----
11668.00		7335.65
=====		=====

FINANCIAL STATEMENTS

INCOME AND EXPENDITURE ACCOUNT  
For the Year Ended 31st December 1982

INCOME		
Membership Subscriptions		7359.20
Ordinary		
- Life Members	19.37	
Application Fees	45.20	
Subscriptions to Journal	7423.77	
Government Subsidy	3061.70	
	1000.00	
Total Membership and Journal Income	11485.47	
Interest Received	8872.16	
Sale of Reprints	386.70	
Sale of Back Numbers	6.00	
Sale of Other		
Publications	25.00	
Annual Dinner Surplus	27.33	
Summer School Surplus	313.67	
Other Income	186.69	
	21303.02	
Less:EXPENSES		
Accountancy Fees	932.00	
Audit Fees	466.00	
Branches of the Society	150.00	
Cleaning	176.00	
Depreciation	523.00	
Electric Light & Power	460.55	
Entertainment Expenses	374.15	
Insurance	202.91	
Journal Publication Costs		
Printing - Current Year	4664.83	
Volume	1002.10	
Wrapping & Postage		
Library Purchases	5666.93	
Library Accession, Cataloguing & Reader	50.00	
Services	131.00	
Life Insurance	433.66	
Miscellaneous	223.55	
Monthly Meeting Expenses	744.23	
Newsletter Printing & Distribution	1217.37	
Postage	280.98	
Printing & Stationery - General	463.80	
Provision for Doubtful Debts	1348.12	
Rent	2781.24	
Repairs & Maintenance	0.00	
Reprints - Loss on Sale	0.00	
Salaries	5149.41	
Telephone	330.84	
	21917.04	
	614.02	
DEFICIT for the year		

## ABSTRACT OF PROCEEDINGS 1982 - 1983

The Annual General Meeting and eight General Monthly Meetings were held in the Science Centre. Abstracts of the proceedings of these meetings are given below. In addition the Liversidge Research Lecture was delivered on 20th May, 1982 by Professor D.P. Craig.

## APRIL 7th

115th Annual General Meeting. Location: the Auditorium, 1st Floor, Science Centre. The President, Professor B.A. Warren, was in the Chair and 35 members and visitors were present.

The Annual Report of Council and the Annual Statement of Accounts were adopted. 3 papers were read by title only. 1 new member was elected.

The Clarke Medal was awarded to Professor William Stephenson; the Edgeworth David Medal to Dr. Martin Andrew Green; the Society Medal to Associate Professor William Eric Smith and the Olle Prize to Dr. Helene Martin.

Messrs. Wylie and Puttock, Chartered Accountants, were elected Auditor.

The Presidential Address "Understanding the Cancer Process: How the Study of the Secondary Deposit Helps" was delivered by Professor Warren.

The incoming President, Professor T.W. Cole, was installed and introduced to members.

## MAY 5th

939th General Monthly Meeting. Location: Auditorium, 1st Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair and 29 members and visitors were present. 1 new member was elected.

A symposium was held with the theme "Development of the Hunter Valley". The panel of speakers comprised Mr. R.H. Read, Officer-in-Charge, Parramatta Branch, N.S.W. Department of Agriculture; Mr. K. Grezl, Research and Development Officer, Hunter Development Board, Newcastle; and Mr. R. Rollinson, Engineer, Projects Planning, Electricity Commission of N.S.W.

## JUNE 2nd

940th General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 17 members and visitors were present.

An address entitled "Electricity Production Using Silicon Solar Cells" was delivered by Dr. Martin Green of the School of Electrical Engineering and Computer Science, University of N.S.W.

## JULY 7th

941st General Monthly Meeting. Location: Room E, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 22 members and visitors were present. 1 paper was read by title only.

An address entitled "Palynology - the Study of Spores and Pollen" was delivered by Dr. H.A. Martin of the School of Botany, University of N.S.W.

## AUGUST 4th

942nd General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 21 members and visitors were present. 3 new members were elected. 1 paper was read by title only.

An address entitled "Higher Education - Only Change is Constant" was delivered by Mr. R.E. Parry, Chairman, N.S.W. Higher Education Board.

## SEPTEMBER 1st

943rd General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 17 members and visitors were present. 4 new members were elected.

An address entitled "Development of Metal Technology and the Use of Metals in Traditional Australian Buildings" was delivered by Associate Professor M. Hatherly of the School of Metallurgy, University of N.S.W.

## OCTOBER 6th

944th General Monthly Meeting. Location: the Auditorium, 1st Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 19 members and visitors were present. 1 new member was elected.

An address entitled "What is a Teaching Hospital?" was delivered by Professor J.B. Hickie, AO, Professor of Medicine, University of N.S.W. and St. Vincent's Hospital.

## NOVEMBER 3rd

945th General Monthly Meeting. Location: Room H, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 30 members and visitors were present. 1 new member was elected. 2 papers were read by title only.

An address entitled "How to Avoid a Migraine Headache" was delivered by Professor M. Anthony, Neurologist at Prince Henry Hospital.

## DECEMBER 1st

946th General Monthly Meeting. Location: Room E, 2nd Floor, Science Centre. The President, Professor T.W. Cole, was in the Chair, and 27 members and visitors were present. 1 new member was elected.

An address entitled "Computer Graphics" was delivered by Dr. D. Herbison-Evans of the Basser Department of Computer Science, University of Sydney.

## CITATIONS

## THE CLARKE MEDAL

The Clarke Medal for 1982 is awarded to Noel Charles William Beadle, D.Sc. (Syd.), Emeritus Professor of Botany of the University of New England.

Professor Beadle has played an outstanding role in the development of Australian botany over the past 40 years.

Firstly, he produced the first authoritative account of the vegetation of western New South Wales (Beadle, N.C.W., 1948: *The Vegetation and Pastures of Western New South Wales*. Sydney: NSW Government Printer). He carried out this work while he was Research Officer and Botanist with the N.S.W. Soil Conservation Service, and the work was embodied in a thesis for which the University of Sydney awarded him the degree of D.Sc. Secondly, he demonstrated the close relationship many plant communities in Australia show to soil phosphate status in their distributions. Thirdly, as a university teacher concerned that undergraduates should be readily able to identify plants, he has been actively involved in the production of regional floras. The first of these is the *Handbook of the Vascular Plants of the Sydney District and Blue Mountains*. This was published in 1963 and arose from his time in the University of Sydney as a lecturer and senior lecturer. This handbook is the direct forerunner of the recently published third edition of Beadle, N.C.W., Evans, O.D. and Carolin, R.C. (1982): *Flora of the Sydney Region*. The second, *Students' Flora of North Eastern New South Wales*, a flora in six parts, of which four have been completed, arose following his appointment in 1954 as foundation Professor of Botany in the University of New England. Lastly, he is author of a volume which will be for many years to come, the definite work on the vegetation of Australia (Beadle, N.C.W. (1981): *The Vegetation of Australia*. Cambridge: Cambridge University Press).

Noel Beadle has inspired generations of students with the breadth and enthusiasm of his approach and his books and many papers have become standard references for professional plant ecologists and for other scientists and persons interested in the Australian vegetation, its distribution, dynamics and history.

It is fitting that he should be honoured for outstanding work, which has continued up to the present time, towards the understanding of the vegetation and flora of this continent.

## EDGEWORTH DAVID MEDAL

Dr. Nhan Phan-Thien is awarded the Edgeworth David Medal for 1982 for his outstanding work in the field of mechanics.

Dr. Phan-Thien is a lecturer in the Department of Mechanical Engineering of the University of Sydney. He graduated from Sydney University in 1975 with First Class Honours, the University Medal and the Charles Kolling Prize, after studying under a Columbo Plan Scholarship. He gained his Ph.D. in 1978 with a thesis entitled "Some Constitutive Equations for Dilute and Concentrated Polymeric Liquids".

He is quite clearly the outstanding young person in the area of mechanics in Australia today. He is astonishingly productive and lives and breathes research, producing 64 papers since 1977, a rate about ten times the norm. The diversity of the research problems treated is very striking, ranging from fluid mechanics to solid mechanics. Dr. Phan-Thien is a very worthy recipient of the Edgeworth David Medal for 1982.

## THE SOCIETY'S MEDAL

The Society's Medal for contributions to the progress of the Society and to science is awarded to William Broderick Smith-White, M.A. (Cambridge), B.Sc. (Sydney).

Associate Professor Smith-White joined the Royal Society of New South Wales in 1947. He served on Council for a total of ten years, being first elected in 1960, becoming President in 1962 and Vice-President in 1963 and 1964. He rejoined the Council in 1971 and served until 1976. In this later period he carried through a complex calculation of the compounded membership fees necessary for a range of ages and length of previous membership. He contributed four papers to the Society's Journal, including his Presidential Address entitled "The Mathematical Sciences in the Changing World".

Bill Smith-White gained his Bachelor of Science from the University of Sydney with first class honours in both mathematics and physics in 1930. He was awarded the Barker Graduate Travelling Scholar-

## CITATIONS

ship in mathematics and proceeded to Cambridge University, where he achieved a Bachelor of Arts after two years' study. Returning to Australia he accepted Professor Wellish's invitation to join the Mathematics Department of Sydney University where he was appointed Acting Lecturer in 1933 and 1934. He was subsequently a Tutor at Melbourne University for two years and returned to Sydney in 1937. There he progressed through various grades, being Senior Lecturer in the 1950's, until in 1960 he was promoted Associate Professor in the specialist field of Analysis. He retired in 1974. His brother, Spencer Smith-White, the plant geneticist, was also at Sydney University for many years.

Bill Smith-White is fondly remembered by his many students for his clear, systematic lectures and pleasant personality. He is also warmly regarded in our Society, and the Council is delighted that he has agreed to accept the Society's Medal.

## OBITUARY

DANIEL JOSEPH KELLY O'CONNELL, S.J.

On 14th October, 1982 at the headquarters of the Jesuit order in Rome, Daniel J.K. O'Connell died peacefully at the age of 86. Fr. O'Connell was elected a member of the Royal Society of N.S.W. in 1935 and published three papers in the Journal and Proceedings. He served on Council from 1946 to 1949 and was a Vice-President from 1950 to 1952. In 1953 he became an honorary member.

Fr. O'Connell was born at Rugby in England on 25th July, 1896. He was educated at Clongowes Wood College in Ireland and joined the Jesuit Order on 8th September, 1913. In 1920 he completed his M.Sc. at the National University of Ireland and was awarded a travelling studentship in mathematics. Arrangements were made for him to enter the University of Cambridge. However, on account of poor health, after completion of his philosophical studies at Valkenburg, in Holland, in 1922, he arrived in Sydney to become Physics Master and Second Division Prefect at St. Ignatius College, Riverview. In 1926, he returned to Dublin to study theology and he was ordained a Jesuit priest on 31st July, 1928. He completed a final year of pastoral theology study from mid-1930 to mid-1931 and then for two years worked at Harvard College Observatory under Professor Harlow Shapley. He completed his Ph.D. studies and returned to Riverview via Mount Wilson and Lick observatories, Japan, China, the Philippines and Java, arriving in December, 1933.

Fr. O'Connell became Director of Riverview College Observatory on 1st January, 1938. The three papers he published in the Journal and Proceedings of the Royal Society of N.S.W. were about earthquakes and the Galitzin seismograph.

However, Fr. O'Connell's main area of study was the variation of light from double stars that revolve round one another and eclipse each other twice each revolution to observers here on earth. These variable stars were observed from Riverview on clear nights and a difficulty arose in constructing a curve of the variation of light with time if the orbit of the lighter star relative to the heavier one was rotating (rotation of apsides). If we are looking along the major axis of the elliptical orbit, the eclipse of the fainter star comes exactly half a period after the eclipse of the brighter star. If, however, we are looking along the line at right angles to the major axis of the orbit, the interval between eclipses will be shorter when the lighter star is nearer the heavier star (periastron) than when it is further from the heavier star. When rotation of apsides occurred, the position of the eclipse of the fainter star by the brighter star moved on the curve of the variation of light with time relative to the position of the eclipse of the brighter star by the fainter star.

Fr. O'Connell studied many eclipsing double stars whose orbits showed rotating apsides, but the O'Connell effect, named after him, is distinct from rotation of apsides. It is that the light maximum following the eclipse of the brighter star is brighter than the light maximum following the eclipse of the fainter star in many eclipsing double stars. Fr. O'Connell considered what he called "the so-called periastron effect in close eclipsing binaries" in a publication of Riverview College Observatory in 1951. It had been suggested in 1906 that a tidal effect occurred between double stars at periastron and, as a result, their radiation increased. However, in 1916, a pair of stars were observed to brighten when they were not at periastron. Fr. O'Connell favoured the explanation that close double stars are embedded in a rotating stream of gas and the stream of gas from the brighter to the fainter star is hotter and brighter than the stream from the fainter to the brighter star. After the eclipse of the brighter star we see the stream of gas from the brighter to the fainter star (in addition to the two stars), whereas, after the eclipse of the fainter star, we see the cooler, darker stream of gas from the fainter to the brighter star.

In 1949, Fr. O'Connell received a D.Sc. from the National University of Ireland. On 26th July, 1952, having just turned 56 years of age, he left Riverview College Observatory to become Director of the Vatican Observatory. Vatican Observatory is at Castel Gandolfo, the Pope's summer residence, on the western side of Lake Albano, 26 km south of Rome. In 1952, the International Astronomical Union met in Rome and Pope Pius XII gave an audience and reception for the astronomers. Later, under Pope Pius XII, the major modern research tool of the Vatican Observatory, the 63/98/240 cm Schmidt telescope, was completed and inaugurated; Fr. O'Connell published a report on this instrument in 1955. From 1955 to 1961, he was President of the Commission on Double Stars of the International Astronomical Union.

In 1957, Fr. O'Connell organized a Study Week of the Pontifical Academy of Sciences on *Stellar Populations*. Pope Pius XII addressed the conference (Fig. 1) and many of the world's most capable astronomers attended it (Figs. 2 and 3). Fr. O'Connell edited the proceedings of the conference in 1958. Also, in 1958, he published "*The Green Flash*", an account of the thin green slit of light sometimes seen for a fraction of a second at the upper edge of the setting or rising sun. In 1970, Fr. O'Connell organized a second Study Week of the Pontifical Academy of Sciences on *the Nuclei of Galaxies*, and he edited

the proceedings of the conference in 1971.

Fr. O'Connell retired as Director of the Vatican Observatory in 1970. He was President of the Pontifical Academy of Sciences from 1968 to 1972. Although he worked very hard, he always had time to talk with friends. He is remembered at St. Ignatius College, Riverview, for showing groups of boys the moon, planets and stars on clear nights and for his unfailing gracious word and cheery smile for staff and boys alike. Fr. O'Connell was very intelligent, hard working and always a gentleman.



Fig. 1. Pope Pius XII and Fr. O'Connell after the Pope's address to the astronomers at the Pontifical Academy of Sciences, 20 May, 1957 (taken by Abbe Georges Lemaître).



Fig. 2. Fr. O'Connell and Professor Fred Hoyle at the Catacombs of St. Callistus, 23 May 1957 (taken by Abbe Georges Lemaître).



Fig. 3. Fr. O'Connell with Professor and Mrs. J.H. Oort at Grottaferrata, 23 May, 1957.

Lawrence A. Drake, S.J.





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